The Smart Home Services Diffusion Process: A System Dynamics Model

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Abstract
The application of smart technologies for domestic environment has been around for a while. But the market diffusion of such products and services has not seen yet a significant growth. This paper seeks to provide an overview of the most important factors that influence the diffusion process of smart home services via literature and a case study. These factors compose a System Dynamics model showing the diffusion dynamics of three main smart home services (Heating, Monitoring, Assisted Living).

1. Introduction

During the last two decades, Information Technology and Internet connectivity have been more and more integrated in people's daily life. This changed the way people live, work, entertain and communicate to each other. (Weiser's Ubiquitous Computing 1991, Ashton's Internet of Things 2009, Ericsson's Connected Homes 2015, Fjord's Living Services 2015, etc.). A promising application secto0r of this new paradigm is represented by the home automation, or Smart home. For instance, a study conducted in 2014 by IDC, a global source of technology market intelligence, showed that 69 percent of all consumers plan to buy a home automation device in the next five years. A smart home in literature is defined as a domestic environment equipped with computing and information technology, which addresses householders' needs such as comfort, control, convenience, security and entertainment (Aldrich, 2003) (e.g. switching on/off the heating, lighting on/off, controlling the appliances remotely and etc.). Smart homes are able to provide users with a large variety of customizable services in order to tailor the domestic environment to their needs (Ricquebourg et al., 2006). The main advantage of smart home services is the ability to be preemptive, i.e. being able to predict any inconvenience and errors, thus avoiding unpleasant drawbacks to the user (Allmendiger and Lombreglia 2005). Therefore the applications of smart home can be divided in four categories: Energy Saving; Support for elderly or disabled; Security and safety; User convenience, among them the user convenience has long been associated with smart services (Holroyd P., Watten and Newbury 2010).
Despite the fact that smart home technologies have been around for a while, their prevalence and diffusion is not widespread, thus their potential is largely untapped. The greatest obstacles to the diffusion of smart home applications are related to: (I) difficulty of integration in existing households; (II) usability, learning and reliability; (III) costs (Tumino, 2015). Hence, the purpose of this paper is to investigate on some of the factors that might enhance the diffusion process of smart home services. Consumers today are exposed to a wide range of influences that include word-of-mouth communications, network externalities, and social signals. In this context, research on diffusion modeling seeks to understand the spread of innovations throughout their life cycle, and

therefore has adapted to describe and model these influences (Peres et al.2010). As Rogers (2003) pointed out, the diffusion of innovation is the process by which an innovation is adopted by a society over time. Kalish (1985) devised an innovation model from behavioral theory, composed by two steps: awareness and adoption. In this model, during the awareness phase an innovation spreads in an epidemic-like way, and is generated by advertising and word of mouth.

The diffusion of technological innovations follows some complex, unexpected and unpredictable dynamics. For ICT companies it is important to adopt a holistic approach, in order to be able to manage the sudden changes in market demand. In this context, SD has proved itself to be an appropriate approach to study the complexity of innovation diffusion processes and a "suitable instrument for decision support in innovation management" (Maier, 1998), precisely because "innovation management comprises all the ingredients of complexity: a large number of variables involved; tightly interrelated in non-linear fashions; and highly dynamic" (Milling, 2002).

In order to contribute to the literature in the application of SD methodology to the field of innovation diffusion,this paper presents an on-going project, carried out in collaboration with Swarm Joint Open Lab of TIM (Telecom Italia S.p.a.) and proposes a System Dynamics model concerning the awareness phase of the diffusion process of selected Smart Home Services.

The paper is structured as follows. In the next section, a literature review is provided on two main streams of research: smart home services and diffusion modeling with System Dynamics. Then, the case study comprising a description of the three services is depicted in Section 3. The SD diffusion model development is presented in in section 4. In section 5 the practical implications and possible use of the model are depicted, and in section 6 discussions and conclusions are drawn.

2. Literature Review

This literature review is divided in two parts. The first part is related to the smart home research arena, and it provides both a contextualization of our research work and the identification of the most promising services. The second part instead provides the theoretical background for the diffusion model, building from previous efforts in the field of diffusion modeling with System Dynamics.

2.1. Related studies on smart home services diffusion

The term smart home has been coined by the National Association of Home Builders (NAHB) in the early 1980s after it set up a group to work for the diffusion of smart technologies in the design of new homes. However, the smart home life envisioned by many researchers since 20th century has yet to deliver. Most of the people are still living in homes more similar to their grandparents' rather than those conceived by the early smart home pioneers (Harper, 2003).

The diffusion rate of smart home services and the factors that can influence it has been the subject of many researches in academic and commercial domains.

Balta-Ozkan et al. (2013; 2014) studied different European smart home markets, which are characterized by different policy and socio-economical contexts and reveals the key barriers to the diffusion of smart home services such as interoperability, reliability, data privacy, control and the cost of the smart home technologies. They illustrate how the age of the building, technical and economical drivers of context can facilitate or create barriers to the diffusion of such services and finally they highlight the need of adopting a more holistic and integrated approach to smart home

services. Wherein smart home services are not limited just to the application of the energy consumption and management products, but also integrated to the other applications such as health, security, assisted living, which can be personalized according to user's need and, thus can bring positive changes in people’s life. Ehrenhard et al. (2014) seek to identify the barriers that are keeping the smart home services limited to a small, luxury and segmented market with stand-alone technologies, despite its potentialities to deliver values to a much bigger market. These barriers are related to meeting end-user requirements, platform management, improved value creation and the role of the government. Furthermore, the organizational and market aspects of Smart Home platform diffusion from a business ecosystem perspective have been investigated in order to provide a generic value network for such platforms (Cusumano, 2010).
In summary, the most important key barriers of the diffusion of smart home services provided by literature are related to the areas of service, user or context. (Table 1)

Table 1: Key Barriers of the smart home services

Area	Key Barriers/Facilitators
Service-related	Interoperability Reliability Control of the service Cost of the service
User-related	Data Privacy Value creation for end-user
Context-related	Technical, economical and social drivers of context The features of the building (age, value, etc.)
Policy-related	Platform management Policy making (the role of the government)

2.1.1 Customer motivations – end-user studies

While some sectors, such as security or air conditioning are widely covered by current services, other areas are still uncovered. In particular, studies show that there is a huge gap between consumer requirements and the products currently available on the market related to energy management for smart home. In particular the delta between the functions undertaken by current smart home services and the functions expected by users is higher than 10% for heating, energy consumption and the remote control of the appliances. The major concern of the smart services for home environment is related to the management of everyday tasks, labor saving and task simplification, ease of operation, remote control and cost reduction (Aldrich, 2003).

Ericsson Consumer Lab (2015) conducted a qualitative and quantitative user research among 1,000 individuals around the world. The result of this study confirms that control, security, interest in new technology and the ability to make life easier are the greatest motivators for the diffusion and usage of connected or smart home services. Cost efficiency has not been a motivator factor (5%), as long as customers need yet to realize the cost saving. Among the factors in more detail, customers declared that the internet connectivity through household wireless connections is a motivator to adopt the technology as long as they are annoyed by seeing appliances cables around their homes; this is also related to the aesthetic factors of the product that might be considered. This study reports also that five individuals out of ten (±50%) show interests toward such services, four out of ten would like to have an integrated connected home service and most of them need services and products related to their health and wellbeing. Women living in large households particularly express high needs for connected home services.
In another similar user-study conducted in 2015, through an online survey by Osservatori.net in collaboration with Doxa, among 1,000 final users, it was highlighted that 59% of them would consider to subscribe services based on information collected by smart objects, with important evidence on safety and damage prevention, but also on remote medical care and remote assistance in case of accidents.

2.2. Modeling the diffusion of innovation with SD

Maier (1998) considers a set of four relevant elements for the diffusion of innovation, one of which can be controlled by the managers. In particular, pricing, advertising, the quality of the product and the delivery delays due to insufficient manufacturing capacity are among the elements that are influenced by managerial decisions. Milling (2002) adds that the diffusion of innovation largely depends on the knowledge of the underlying technology, which he regards as the result of an evolutionary process. The maturity of the technology is instead a key innovation driver for Tsai and Hung (2014), along with service maturity, price, perceived risk and the macro-economic situation.
SD has been already applied in various domains of research with the purpose of observing and exploring diffusion behavior of an innovation system. For instance it is applied to diffusion process of energy efficiency lighting in households (Timma et.al., 2015), on alternative fuels vehicles in order to predict the future market of such vehicles (Shen and Ma, 2013), and to the innovation diffusion of multi-generation products (Lo, et.al., 2011). While Kreng and Weng (2013) introduce an integrated multi-generation diffusion model, thus considering dynamics of the potential market accounting the relationship among generations and products, Ryan and Tucker 's work (2009) focused particularly on the diffusion of the videocalling technology. In the latter, authors investigates how different types of heterogeneity (e.g. adoption cost, network effects, usage) affect network evolution and so the diffusion of the product. Finally, Tsai and Hung (2014) apply system dynamics to investigate the diffusion of cloud computing.
The coaching reference model for these previous works as well as this research is the Bass diffusion model (1969). In this model, users can adopt first as a consequence of the advertising by the company that provides the services:

$$Adoption\ rate\ from\ advertising\ =\ a * P \qquad \text{Equation 1}$$

Where P is the population of Potential adopters at each time step and a is the advertising effectiveness (adoption fraction from advertising).
The adoption from word of mouth can be modeled as follows:

$$Adoption\ rate\ from\ word\ of\ mouth\ =\ c * i * P * A/N \qquad \text{Equation 2}$$

Where c is the contact rate between individuals in a population, measured in people contacted per person per time period, i is the adoption fraction from word of mouth, A is the population of Adopters, and finally N is the total potential market. Potential adopters generate as much as cP contacts for each period. Potential adopter interact with adopters and the probability that each potential adopter has to get in contact with an adopter is the fraction of total adopters A/N. Therefore, the total amount of interactions between adopters and potential adopters for each time period is cPA/N. However, only a portion i of these interactions turns out as a successful adoption.

3. Smart home services

This research has been proposed by Swarm Joint Open Lab, a group within TIM Open Innovation, to challenge the modeling of the diffusion of three main services related to Smart Home: Monitoring, Heating and Assisted Living. The goal was to investigate how these services could be spread into the market, with a particular focus on the Italian customers, also taking care of transversal service interactions (cross-selling) and different factors that might influence this adaption, whether user-related, context-related or service related. And finally to understand the interaction between the adopted service and others.
The smart home services under examination are depicted in the following subsections.
Heating service: The energy consumption in buildings has steadily increased since 2008. In particular, buildings sectors energy consumption has grown at a faster rate than the industrial and transportation sectors and it requires a considerable amount of the primary energy usage in developed countries, representing 20% to 40% of the total primary energy consumption (Perez-Lombard et al., 2008). Thus the performance and efficiency of space heating systems become crucial not only for improving inhabitants' comfort but also for reducing energy usage purposes (Ren, 2015).
The service consists in the remote control of the temperature and the possibility to save on energy bills by avoiding an overheating when the user is out and enabling preheating of the space for user's thermal comfort when come back home.
Monitoring service: Home security and personal safety are major concerns for individuals. People want to protect their valuables and provide a safe haven for family members and loved ones. Traditional home security systems generally alert the neighborhood with a loud noise warning the intruder(s) that the invasion has been detected. In addition, home alarms generally inform a home security central system of the unauthorized entry. The home security central system then may alert the police and/or third party security companies. Home security devices generally involve a kit of window detectors, door detectors, motion sensors and other devices (Saylor et al., 2003).
The service within the modelling framework consists in a system and method for connecting a security system to a wireless communication system to automatically inform the owner and other authorized entities. This function must be predefined by the user when alarm worthy situations

occur. It allows the individuals to remotely monitor the internal and external of the house at any time.

Assisted Living service: The increased life expectancy and the growth of the older adult population have led to new models of aging that empower people to fulfill their lives in their homes (Demiris, 2008). (Pragnell et al., 2000). Researchers have demonstrated that the smart home information technologies (IT) in residential care (RC) facilities are performing tools to enhance resident quality of life and safety (Courtney, 2008). Smart home services aim indeed to be a promising and cost-effective way of improving home care for the elderly in a non-obtrusive way, allowing greater independence, maintaining good health and preventing social isolation. (Chan et al. 2009).

The service provides assistance for elderly in their home, throughout the day by using devices, the fast and direct connection to caregivers and the emergency services such as the ambulance.

4. Model development

The main objective of this research project is to understand the levers that enable the adoption growth of the smart home services by users. To this end, we adopted the Bass diffusion model for each of the three services. However, the Bass diffusion model has been adopted only as a funding reference. Our objective is in fact to model the awareness on the service, rather than the adoption. Hence, we argue that for a very innovative service advertising works as a factor enhancing awareness in the first phase, and only in a second phase as an adoption factor. Moreover, we do not introduce the price of the service in our model, given the fact that no historical data is present for fitting the model, and furthermore price usually is not a factor for increasing awareness during the diffusion process (Kalish, 1985).

To the original Bass model we introduce the notion that the services are connected so that the diffusion of one service may support the diffusion process of another one. We model this by introducing a cross-selling adoption variable, repeated for each service. Finally, we model the awareness process on the total number of households rather than individuals.

4.1. Structure of the model

The proposed model integrates the basic structure of the Bass diffusion model with the cross-selling variable. The structure of the model is shown in Figure 1.

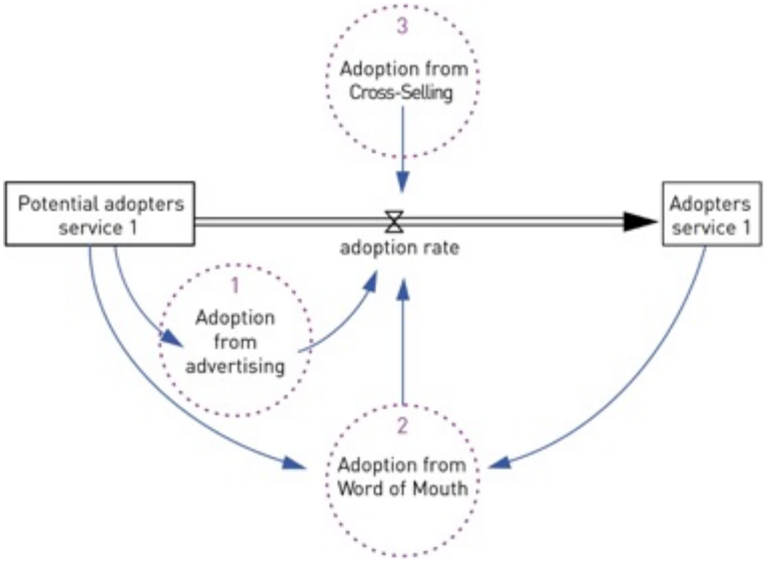

Figure 1 - General structure of the model

In our model, the adoption from advertising resembles the definition by Bass, as seen in Figure 2.

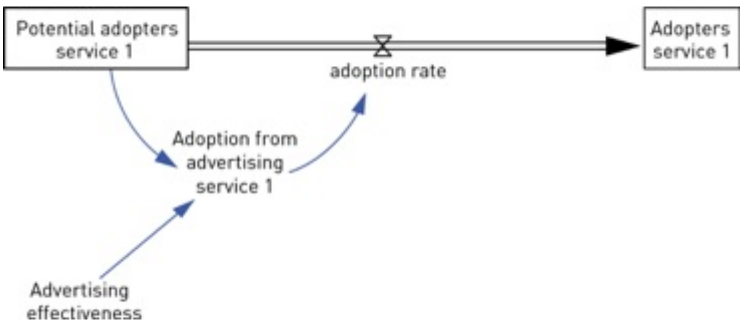

Figure 2 - Adoption from Advertising

Adoption from word of mouth (Figure 3) works similarly to the Bass diffusion model. However, we have computed two different potential markets depending on the features of each service. Nevertheless, this service can be delivered only to households with a Wi-Fi connection; hence for all three services the initial potential market is the following:

$$N = \%\, wi - fi\ connected\ families * H \qquad \text{Equation 3}$$

Where H is the total households. However, a further refinement was made for the Assisted Living (AL) service, as per equation:

$$AL\ potential\ market = N * \%\ of\ households\ with\ elderly\ people$$

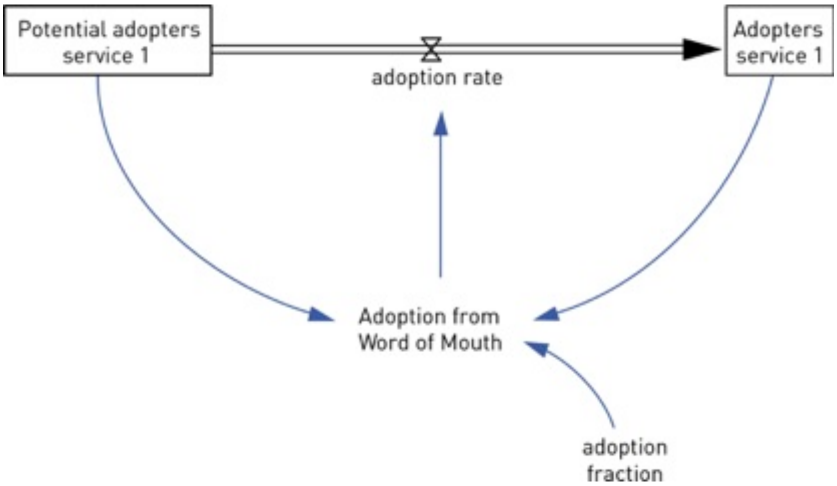

Figure 3 - Adoption from Word of Mouth

Finally, the adoption from cross-selling should represent the users that adopts one service if they have successfully adopted, used and liked another one. Adoption from cross-selling works with similar dynamics for each of three service. In fact, the adoption of one service supports the adoption of another one by means of a parameter named *degree of compatibility.* This parameter measures the frequency to which users integrate the already adopted service with another one.
The adoption from cross-selling is shown in Figure 4.

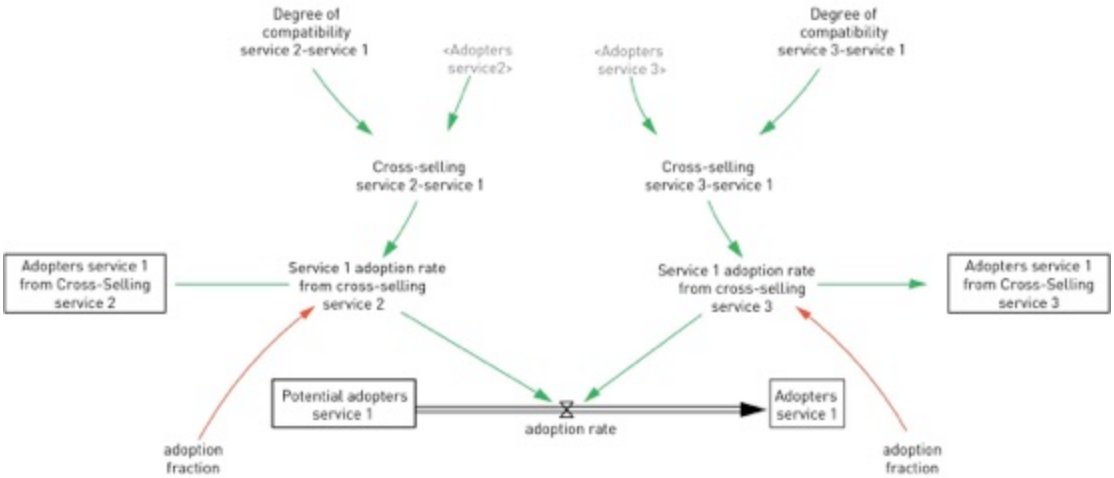

Figure 4 - Adoption from Cross-selling

$$Service\ 1\ Adoption\ rate\ from\ cross-selling\ from\ service\ 2 = Cross-selling\ Service\ 2\ -\ Service\ 1 * Service\ 1\ Adoption\ fraction$$ Equation 4

Where *Cross-selling service 2-service 1* represents the amount of users that have already adopted service 2 and might integrate with service 1 as well. This is equal to:

$$Cross-selling\ service\ 2 - service\ 1 = Adopters\ Service\ 2 * Degree\ of\ compatibility\ Service\ 2 - Service\ 1$$
Equation 5

4.2. Adoption from Word of Mouth

For this component of the diffusion model, the original Bass diffusion model was integrated with the adoption factors peculiar of the service that could enable or hinder its adoption. These factors are related to the different features and scope of the three services. In fact, they aim to appease different users' needs and hence their adoption is driven by various motivations which have to be taken into account for the model development.
In our model, these differences are accounted to model the adoption fraction, which is not a unique figure but rather the parametric result of a combination of various effects.
For instance, the Heating service will be as captivating to users as its effectiveness in terms of energy consumption reduction and level of comfort provided. Hence, the heating adoption fraction is the summation of two parameters, as seen in equation 6:

- Total energy net savings, measured as the difference between the kwh saved and the price of the service;
- The level of comfort provided, measured as a dimensionless parameter

$i\ (Heating) = \ Comfort + \ Net\ savings$ Equation 6

The value of these parameters can be studied from two different perspectives.
On a micro-level made up by the individual adopter, they may represent the relative preferences of one factor over the other. That is, the threshold level of one parameter over which the individual potential adopter will not adopt the service. For instance, is there a Comfort level sufficiently high, able to counterbalance a negative Net savings, so that the service can still be attractive to the user?
On the other hand, on an aggregate market-level composed by all potential adopters, the values of the parameters might measure the share of users that make their adoption looking at one parameter over the other one.
The heating adoption from WoM is shown in Figure 4.

Figure 4 - Heating Adoption from Word of Mouth

The second service in the diffusion model is the Monitoring service. As stated, it uses several sensors and camera to provide general information about the activities of people and resources in the home environment. This means that it will be effective on the expense of a little bit of privacy that the user

is willing to give up on. For the model development this translates into the calculation of the adoption fraction as a combination of some positive and negative factors.
A parameter named “Privacy” depicts the user willingness to adopt the service even though, it requires a lower level of data privacy. Then, we argue that security services will be more attractive to users in location where the police force is quick and effective (*Enforcing effectiveness*), and the crime rate is high. Moreover, we introduce a parameter, Building characteristics, that comprises the factors that might induce the user to feel less safe, such as the distance from one’s workplace or the economic value, and the age of the building.

$$Building\ characteristics = \\ Distance\ from\ workplace + Economic\ value - Age\ of\ the\ building)/3$$

Equation 6

The formula for monitoring adoption fraction is shown in Equation 7 below.

$$i\ (Monitoring) = \\ Enforcing\ effectiveness + Crime\ rate\ of\ the\ area + Building\ characteristics - Privacy$$

Equation 7

The monitoring adoption from WoM is shown in Figure 5.

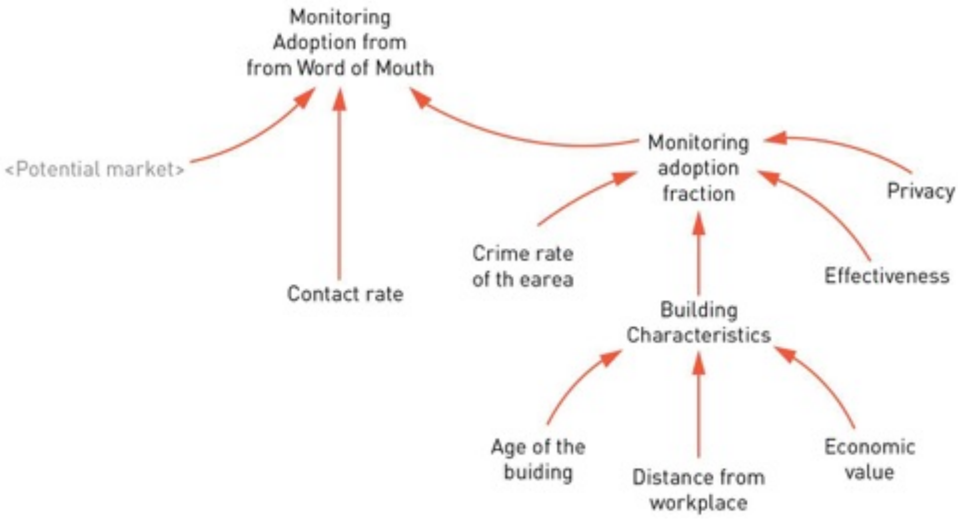

Figure 5 - Monitoring adoption from Word of Mouth

Finally, Assisted living provides ambient assisted living for fragile people through real time information about their health parameters. For this reason, the service leverages on two parameters.
First, we argue that there is a need to install more sensors within the domestic environment and also use the wearable devices in order to collect health parameters. As a consequence, some users could find this service too much invasive for the person living in the house.
Second, a risk factor exists to depict the degree of potential threats to the state of health of the person living in the house. This factor should include the propensity of the elderly people to incur in domestic accidents or their declining health.

The formula for Assisted living adoption fraction is shown in Equation 8 below:

$$i\ (Assisted\ Living) = Risk\ factor - Invasiveness - Privacy \qquad \text{Equation 8}$$

The assisted living adoption fraction is shown in Figure 5.

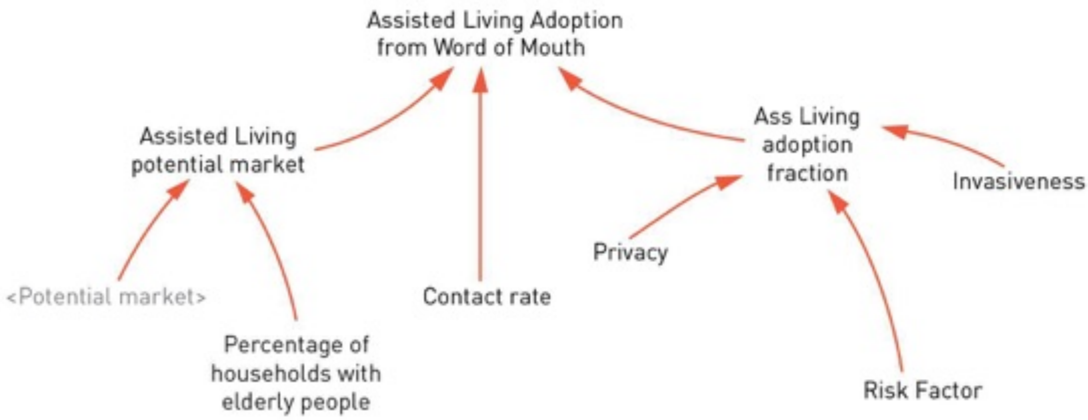

Figure 5 - Assisted Living Adoption from Word of Mouth

4.3. Calibration of the model

The model has been calibrated with three types of parameters. The first type refers to the context where the service has been launched. The second and third types of parameters instead, instead, pertain to some features of the service and the users' stand and preferences towards these characteristics. For the purpose of this paper, we could calculate the values only for the context-related parameters. The values are computed for the city of Turin, Italy. Turin has the population consisted of 902'137 inhabitants, is an industrial city located in the north-west of Italy, with an annually per capita income of roughly 23,000 €.

Type of parameter	**Parameter**	**Influence on the adoption process**
Context-related	Enforcing effectiveness	Positive
	Crime rate of the area	Positive
	Risk factor	Positive
Service-related	Kwh saved	Positive
	Price Heating	Negative
	Advertising effectiveness	Positive
	Incentives from insurance company	Positive

User-related	Comfort	Positive
	Privacy	Negative
	Age of the building	Negative
	Economic value	Positive
	Distance from workplace	Positive
	Invasiveness	Negative
	Contact rate	Positive

We retrieved the value for the context-related parameters from multiple sources. Crime rate of the area is computed as the percentage of households victim of theft (elaboration from Urbes, 2015). In Turin, 5,742,burglary were committed in 2014 (636.5 house robbery per 100,000 inhabitants). Stating that 415,414 households live in Turin, the parameter Crime rate is equal to:

$Crime\ rate\ = 5{,}742/415{,}414 = 0.014$

Enforcing effectiveness is calculated as the percentage of burglars found guilty of house robberies. This rate is equal to 2.6% for the region of Turin (we could not retrieve more detailed data on the city level).

Finally, risk factor is computed as the frequency of falls of elderly people, as a proxy of how risky it is to leave an elderly person alone in the house. This parameter is equal to 10.25% for the region of Turin (Epicentro, 2013).

5. Implications and practical use of the model

The proposed System Dynamics model could serve a handful of purposes.

Through system dynamics methodology it was possible to frame the diffusion problem, and identify what are the most important external factors that influence the diffusion of an innovative service. Regarding this point, the model supports the identification of the most promising markets as a consequence of these external factors and their influence on the diffusion process. For instance, smart home services can be more popular in cities where the crime rate or the enforcing effectiveness represents higher values.

Then, the model provides a proper tool for monitoring the diffusion process. Firms can perform ex-ante simulation and create a benchmark and then assess the actual performances on the predicted ones, so to validate hypotheses on the user's behavior. As a matter of fact, the diffusion curve returned by the model can be fitted against actual data, by modifying accordingly all the user-related and service-related parameters. This fine-tuning process can be performed periodically for more and more accurate predictions. However, for this particular implication of the model, we have to assume that the relation between the context-related parameters and the adoption fraction is linear.

This model can show the dynamics of the diffusion by end-users among different services, showing that the diffusion of one service over the others can influence the diffusion of another connected service. Then, this model can be used to evaluate how the process of cross-selling might develop, and therefore from a company's perspective insight can be drawn over which service should be introduced or offered first.

6. Discussions and conclusions

During this research work we have identified some enabling factors for the diffusion of three smart home services, further assessing the relation, positive or negative, between these factors and the diffusion. We have divided these factors in three categories, and provided numerical calculations for one category of factors, namely the context-related.

We applied the Bass diffusion model for the awareness phase of a diffusion process, showing that the proposed model is able to provide insights on the most promising markets. Moreover, it can be used to monitor the diffusion process, as well as test hypotheses on users' requirements and behaviors, especially in terms of interconnections between the services. However, user and service related parameters can be assessed beforehand, through a sound market analysis on the users' requirements, in order to build a more predicting model.

Further development of this project will be the validation of the relation between context-related parameters and adoption fraction; with real data inputs from end users and field studies. Context-driven data can be changed according to a particular city with its peculiar characteristics, in order to understand the dynamics of the innovation diffusion within the city under examination. In this way the model will be adapted accordingly. Other factors will be also implemented in the model such as the user's dropout rate. A model focusing on the adoption step of the diffusion process is out of scope of this preliminary work and will be tested in future developments, since it requires further information on the price of the service and the risk-taking attitude of the potential users.

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