Socially Assistive Robots Diffusion in Elderly Care

A pre-adoption study through Agent-Based Modeling

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Abstract— This paper investigates social assistive robots' acceptance and diffusion in eldercare from dependent-living seniors' perspective by combining data science with the agent-based model of cellular automata, able to unveil the emergence of behavioural pattern in a complex system, as result of individual agent interactions. The ratio behind this methodology is that, while social dynamics are often underestimated, they are determinant for the success of an innovation, especially in a pre-market context, in which users do not know the product. In this way, by looking at how opinions are formed and word of mouth circulates among social agents, this paper identifies a cluster of enthusiast seniors, which, if properly addressed, could behave as social hub and influence innovation success. At the same time, however, this work unveils the presence of extremism and negative word of mouth, which, in turn, can lead to innovation rejection.

I. Introduction

Since its foundation, the Marketing science struggles to understand human behaviour on the marketplace. On individual level, each case is, in fact, unique and its choices seem to be the result of a random set of circumstances, impossible to predict. However, on a macro-level, it is possible to observe patterns of behaviours: order structures emerging from chaos. One of the most fascinating and relevant examples of such emergent patterns is innovation diffusion. Many products fail shortly after their market launch by reaching a lower market share then expected [16], but, while many studies focus on modelling innovation diffusion after market entry, few address the pre-market phase, which, if properly managed, could lead to significant savings. Experiments, like the studies on hybrid corn diffusion [34], have proved that social influence has a large impact on innovation adoption [16,19,31,32,34,38]. The market percolation phase transaction, so, can be explained not only in terms of number of buyers [1], but also network of connection and nature of interactions [17]. In this way, complex system theory and opinion dynamics offer an interesting framework to study diffusion, especially in a pre-market setting. This paper defines complex systems as "systems composed of multiple individual elements interacting with each other, yet whose aggregate properties or behaviour is not predictable from the elements themselves" [47]. By describing the marketplace as a complex system, it becomes clear how each individual is embedded in the system and, therefore, subject to its rules, since, as the "butterfly effect" [29] reminds us, even a small status change could seriously affect the whole system in the long run. From individuals interaction emergencies i.e. "novel and coherent structures, patterns, and properties" [47] arise. In this way, the ultimate marketing goal becomes to study conditions beneath agent interaction within the marketplace. To this purpose, new modelling approaches arise, like Agent Based Modelling (ABM), which allows representing the world into a multiplicity of randomly distributed agents, subjected to certain rules, in order to unveil the mechanism behind behavioural patterns and drivers of change in the system. This paper will combine a special class of ABM simulation methodologies, namely cellular automata (CA), with data science to investigate the chances of success and rooms of improvement of social assistive robots diffusion in institutionalised eldercare settings.

II. Social Assistive Robots

A. Overview

Over time, researchers, scientists and thinkers wonder about the possibility of reproducing the flexibility of human mind. However, the concept of intelligence has shifted during years. Until late 1980s problem-solving ability was at its very core and cognitive processes like playing chess, were used as exemplification of human intelligence, in order to build machines able to either simulate or exercise it. Soon, however, a new perspective arises: studying intelligence as the interaction between the subject and the environment. This shift from problem-solving mind to mind in the body [4] has significant implications for research in Artificial Intelligence (AI), by leading to the new paradigm of *behavioural-based AI* [42], and to robots able to interact with the environment and answer to certain stimuli. By the mid-1990s this perspective evolves and researchers [4,5,6,7,8,9] underline the importance of *social collective intelligence*, the cornerstone of researches in human-robots interaction [4]. This concept aims at emphasizing the social dimension in developing human intelligence: if primate intelligence evolves in adaptation to complexity [12,13,14,15], human-like intelligent machines should be able to adapt and interact with the environment by answering external stimuli. From this new perspective, social robots arise as one of the innovations with the highest potential and risk of our age. One particular category of social robots is Socially Assistive Robots (SAR) defined as intelligent machines created to provide assistance to users through social interaction and physical assistance. Nowadays, the interest for this category is growing, in light of Active Assisted Living (AAL) field, as possible solutions to social emergencies, like the aging issue.

B. Social Impact

These SAR and AAL systems, in fact, can perform a variety of tasks by offering interesting opportunities in fields like physical rehabilitation, personal assistance and medical care. Particular literature identifies two relevant macro-tasks, i.e. emotional expression and daily-life support [17]. On this basis, it is possible to distinguish between companion robots, keen on emotional stimuli, and service robots, which offer daily-life support [49]. This paper will mainly focus on service robots, due to their higher relevance for the chosen target, i.e. frail-elderly without cognitive disabilities.

In this way, SAR offer personal support through three main functions [36]:

- *Daily-life Assistance* to users in their daily activities through *reminder function* (SAR help the users in time-planning and organization, they keep an updated schedule of users' activities and remind him/her events, appointments, duties and deadlines) and *fetch and carry ability* (capacity of moving or bringing objects, foods, drinks)
- *Monitor* physical conditions of users and their safety, by warning help in case of need.
- E*ntertainment* the users by socially communicating through voice, dialogue, gesture, facial expression and by using a variety of media tools like videos, movies, games, music, telephone. To perform effectively such functions, it is necessary to work on the most relevant dimensions for human-robot interaction [18]:
- Design (anthropomorphic, zoomorphic, caricatured or functional), impacts on first impression, affects opinion formation and the way users will interact with the machine.
- Personality, indicates "the set of distinctive qualities of an individual" [18] and impacts on opinions through emotions i.e. ability of the machine to recognise emotional cues and express them and intelligence i.e. ability of learning, as well as human-oriented perception and intentionality.
- Language i.e. the ability to communicate passively and actively through both verbal and para-verbal skills (body language, facial expression) has a great effect on robot perception and interaction possibilities.

The ethical impact of SAR has been however largely debated [35,36,37,39,40,43,44]. While some consider these robots as the ultimate solution for elder welfare, others look at them as dangerous threats for eldercare quality. To briefly simplify the complexity of such debate, it is possible to identify 5 main dimensions relevant to assess SAR social impact: (1) autonomy and independence, (2) security, (3) privacy, (4) isolation, (5) dignity. If these systems aim to bring a real contribution they must aid independence through a user-centred design without compromising safety and guarantee transparent data collection through informed consent. Furthermore, they cannot substitute human contact, since this would affect human dignity and increase loneliness, which in turn can lead to diseases like Alzheimer [27].

III. Theoretical Background

A. Social Percolation

Modelling innovation diffusion is one of the most relevant and fascinating issues in marketing studies. Over time, different approaches have been developed. In particular, we can underline three main streams of research [25]: firstly there are phenomenological models of diffusion, derived from Bass work [1], able to reproduce sales dynamic through parameters fit; secondly micro-modelling, which interprets innovation diffusion as results of individuals' rational decision making process, driven by the "interplay of expectations and maximization" [25]; thirdly and finally, there are stochastic micro models, which look at collective phenomenon (emergencies) as consequences of individual decision making. These latter models, which constitute the focus of this paper, derive from the spatial stochastic process of percolation. Born from a physical phenomenon of fluid movement through porous material, percolation is the diffusive process of deterministic movement through a random medium [19,31,38,48], in contrast with phenomenological models, which focus on innovation diffusion as random movement in a non-random medium. In other words, given a network of elements or "agents" with specific properties and initial status, within a percolation regime the interaction, or connection, among agents is determined by a certain set of rules, which include both internal and external factors. While the agent's initial status is determined, the elements location and connection are randomly assigned, by originating a random medium structure. On the contrary, in traditional models of diffusion like the Bass model, individuals' specifications are absent and there are no rules beneath agents' interaction at micro-level: the medium through which the innovation propagates presents, in this sense, a non-random structure. One of the main properties of percolation regime is to be essentially "decentralized": the global dynamic is not defined "a priori" but emerges as results of agents' interaction [2]. To sum up, in contrast with the traditional phenomenological models, percolation does not adopt a mathematical-based approach but a computational one: instead of moving from utility functions or equations, percolation requires rethinking problems in terms of heuristics, rules and procedures, which agents used to make decisions [32]. In this way, Agent-Based Models, a form of computational modelling whereby a phenomenon is described in terms of agents' interactions [47], is one of the best stochastic micro models to describe innovation diffusion as percolation phenomenon.

B Percolation versus traditional diffusion model

This paper approaches innovation spread as percolation and adopts Agent-Based Modeling instead of the more traditional Bass Model of diffusion. The structural difference between percolation, as deterministic movement through a random medium, and traditional diffusion, as random movement in a non-random medium, has been depicted. However, before moving forward, it is necessary to better distinguish between these two approaches, in order to make clearer the ratio behind this paper choice.

Firstly, we briefly remember that, while there are many studies on quantitative modeling of the time-profile of the diffusion process, this paper has a different focus: it aims to investigate the starting phase of an innovation, by looking at the moment in which the product is not on the market yet, in order to analyze how people come to be aware of it. Therefore, this paper goal is to analyze the Word Of Mouth (WOM) dynamics, for understanding how information circulates in a social group and opinions are formed, before the innovation actually enters the market.

By following Rogers' diffusion theory (1962), Bass model emphasizes the role of two main sources of influence on probability of adoption: external (e.g. advertising and mass media) and internal (e.g. WOM). In this way, through the conditional probability of adoption at time t is expressed as follows:

$$f(t)/[1 - F(t)] = p + qF(t)$$

In the formula, f(t) is the probability of adoption at time t, F(t) is the cumulative probability of adoption at time t, p represents the internal influence and q the external one. [1,19] The Bass model is widely accepted, fits well many data and finds its root in the well-known innovation diffusion theory. Over time, the model has been extended to include for example marketing mix, competition, repeated purchase [19], however these aggregate models assume homogeneity in the communication behaviour of adopters [19] specifications at individual level are absent and the impact of micro-level factors on macro-level phenomena remains unclear [10].

In ABM within the percolation framework, agents are inserted in network structure with different number of connection [32], initial state (e.g. buy/not buy) and peculiarities, summarised in the variable individual preferences (pi), and are subjected to certain rules which govern the changes of state at micro-level [10]. In the model this paper deals with, each agent corresponds to an active or passive node in the network. Changes of state can happen only when there is a link between two nodes or, in other words, if there is an interaction between agents with different state. In this case, the active node will communicate through WOM with the passive one, which, at that point, will choose to update its state or not: spread of information and the actual state change dependent on the social influence are, in fact, two different phenomena. It becomes clear that, in this approach, WOM is the privileged communication channel through which information propagates, which is useful for our goal. In this way, this paper will consider not only positive effect of the word of mouth (PWOM) but also the negative one (NWOM), which has been identified as more informative and stronger then the PWOM since it may be contagious and spread independently from the exposure to the product [16]

Further advantages of this approach are that it provides an easy way to incorporate randomness in the model and therefore to represent complexity, It enables models construction in absence of knowledge about system global interdependencies and it is easy to maintain since models refinements act on local interaction [2].

To conclude, ABM and percolation approach have certainly limitations, like the computational complexity, individual-based knowledge required [33], the network structure, which is a discriminant choice for the final result. However, this methodology allows our work an extensive degree of heterogeneity at agent level, the possibility of building a very granular model of the social communication process topology [32] and the ability to look at the macro-effects of micro-behaviours [19]. Such possibilities offer high potential for our work since it is our belief that in a pre-market settings, for a social innovation with high impact on people life, like SAR, the comprehension of micro-behaviours and WOM dynamics is fundamental to prevent not only the market fail, but also an unethical introduction of the innovation, unable to consider final users' wants and expectations. Furthermore, it is interesting for us to examine the possibilities that ABM offers for innovation diffusion and marketing studies, since it is still uncommon for this research field.

C. Applicability

There are six main factors for evaluating the applicability of ABM [33]:

- *Medium Number of Agents* [3]: ABM better works when there is a number of agent "big enough that no agent determines the system final outcome but small enough that a group of population can significantly affect the outcome" [33]. In this way, ABM enables monitoring of every agent in the system.
- *Complex but local interactions:* ABM is not useful when all actions are the same or have the same global impact. It is, however, valuable when dealing with complex, local interactions, which can be history or property dependent. Information, anyway, is not transmitted outside the network.
- *Heterogeneity:* as discussed above, this is one of the main features of ABM; agents are not all the same, they have specific properties and different ways of interacting.
- *Temporal aspects:* all agent-based models feature time, looking at how agents take decision over time in a dynamic and changing environment. It is not a sufficient condition but it is necessary for ABM models.
- *Adaptability:* an agent is adapting if, when confronted with the same circumstances experienced in the past, takes different actions based upon learning. It is a powerful ability to incorporate in a model, in presence of such conditions opting for ABM modelling becomes almost necessary.

- *Rich Environment:* ABM offers many possibilities for representing environment agents inhabit. For example agents may be located in an abstract social network but also in a real geographical space, which could even have its own rules.

IV. THE MODEL

A. Opinion Formation

The user is the starting point for agent-based modelling. In this way, the first step to build a model of opinion dynamics has been to identify drivers of social robots acceptance from seniors' perspective. This process has been done in order to derive a behavioural equation behind the binary decision of adoption (pro/contra). To this purpose, acceptance factors have been identified from literature [22,23,24] and adapted to our case in order to study opinion formation.

TABLE I. ACCEPTANCE FACTORS

Code	Description	Construction
ANX	Anxious or Negative emotional reactions to the system	I am afraid the robot makes mistakes I am afraid the robot would make me dependent I am afraid the robot would affect my privacy I find the robot scaring I find the robot annoying I think only young people can understand this technology
ATT	Personal attitude towards the technology	I am interested in this technology I like to be innovative
PEOU	The degree to which users believe a system is easy to use	I think I can use the robot with a good manual I think I can use the robot without support
PENJ	Perception the system could be enjoyable	I think the robot is enjoyable I think the robot is nice The robot seems living I think the robot is sociable
PU	The feeling the system could be useful, adaptable and reliable	I think the robot is useful for me I think the robot is conform to what I need I think that the robot is reliable
SI	The degree to which others affect decision about technology	I would use the robot if my friends/family suggest it I would use the robot if my doctors/carer suggest it I would use the robot if experts suggest it I would use the robot if someone using it before suggest it
TRUST_SOURCE	The trust in the source of information about the technology	I trust my friends/family I trust my doctor/carer I trust experts I trust people already trying the technology
TRUST_MESSAGE	The trust in the message received about the technology	I think the information is clear I think the information is reliable I think the information is relevant
WOM	The attitude to spread word of mouth	I like to talk with my friends about new products I often suggest new products to my friends

B. Opinion Dynamics

This paper applies a particular class of ABM namely cellular automata CA, for investigating SAR percolation chances. There are some basic principles or assumptions distinguishing cellular automata:

- *Spatial Structure* "Cellular World": agents are positioned in a specific structure, commonly a checkerboard, in which every cell corresponds to a specific location.
- *Specific* meaning for *local interactions*: individuals can only interact with others in close-distance. There are many different ways for representing neighbourhoods, the most common are Von Neumann, with four neighbours per cell, and Moore Neighbours with eight per cell.
- *Initial State and Opinion Dynamic*: Agents have a state (Si) corresponding to specific opinions or features, which can change according to the neighbours opinions (Sj).
- *Time is discrete*: times moves in steps or rounds; in some models, each agent will change his/her status simultaneously, in others agent update opinions one at a time.

The ratio behind this model involves different social phenomenon like Gabriel Tarde's imitation principle "do as the other do" [41], which is based on two phenomena [45]:

- Bounded rationality: in many situations agents lack objective information about a phenomenon and therefore deciding to imitate others. In this sense also conformity and social influence may be ascribed to the imitation phenomenon.
- Externalities: following the majority might bring advantages.

Initially system has been set with the (a) classic assumptions of cellular automata:

- Agents are positioned in a social system with a Von Neumann neighbourhood (each agent is located in a cell with four neighbours).
- The social system is represented with a four lattice structure 50x50.
- Information can be passed only when there is a link between two agents.
- The spread of information and the social dynamics are two different phenomena.
- Agents have an initial status/opinion (Si), which may vary according to neighbours' opinions.
- At t1 all agents update their status at the same time.

In order to determine opinion dynamics, it is necessary to unveil the rules behind state changes of agent. Such change is dependent from the state of neighbours at the previous time step and from the probability the agent will choose adoption.

In order to compute such probability a binary logistic regression based on the determinant of adoption has been used by applying the following formula:

$P= 1/1+e^{-(a+b_1x_1+b_2x_2+\dots b_nx_n)}$

Before moving forward we summarise the hypotheses concerning opinion formation to be tested by the study:

H1 Initial opinion configuration is heterogeneous

H2 Attitude (ATT) and Social Influence (SI) are expected to be the main determinant on preference of agent pi

H3 Anxiety, Perceived Usefulness, Perceived Enjoyment and Perceived Easiness of Use are expected to impact Attitude toward SAR innovation

H4 Tendency to spread WOM, Trust in the source and content of information, Education are expected to impact SI

V. The Experiment

A. Participants Selection

The experiment has been conducted through an on-field study. In particular study sessions have been organised in 11 senior homes belonging to two Austrian networks: Kuratorium Wiener Pensionisten-Wohnhäuser (9 homes) and Alten-.und Pflegeheime der Kreuzschwestern (2 homes). The sessions have been organized following specific criteria, here briefly reported. The study has been conducted on a convenience sample of 131 respondents over 60 years old, living dependently in Austrian senior houses. In order to collect realistic opinions, voluntarily expressed by participants, three conditions have been given to senior houses management staff to select participants:

- Absence of drastic physical impairments: selection of participants able to provide to the most basic needs like in specific bathing, dressing, using toilet, eating, drinking and walking (even with some tools for support)
- Absence of severe cognitive impairments: selection of participants in full possession of one's faculty.
- Consensus to take part in the study: participants have been informed in advance about the study topic and agreed whether to collaborate

B. Robot Selection

For the study, the robot Care-O-Bot 4©, developed by German research institute IPA of Fraunhofer Gesellschaft, has been selected as example. The robot aesthetic and functional design, the imminent market launch in 2018 and the geographical proximity between the German and Austrian market have been considered as drivers for the selection. Care-O-Bot 4 © profile and key abilities are summarised below.

TABLE II. Care-O-Bot 4© Profile

Design	Technical Schedule	Technical features
	**High**: 158 cm **Weight**: 40 kg **Max Speed**: 1,1 m/s **Interface**: 7'' Touch Screen **Degrees of Freedom**: 29	**Movement**: autonomously moving and charging, obstacles recognition, bowing down **Commandos**: vocal and gesture recognition, touch-screen **Functions** - Assisting: taking and bringing objects - Monitoring: reminder function, calling help in case of emergency - Entertaining: interactive communication, multi-media access (video, pictures, games)

C. Material Selection

Images and video material have been selected from Fraunhofer Gesellschaft IPA website with their consent. The video material was more emotional then explicative, but being merely used as introduction, has been considered adequate for our purpose. Functionalities have been then illustrated. In the survey, questions about video reliability, credibility and relevance have been inserted.

D. Session Organisation

For the study, a group session was organised in each senior house. It was structured with a brief presentation (20'/30') of project goals, survey rules and interface presentation through visual support (images and video) followed by a Q&A panel and the survey distribution. In order to guarantee attention and support for the survey, the number of participants ranged between 10 and 20 and the maximal duration scheduled was two hours.

E. Data Processing

This paper mainly follows a quantitative approach based on a 5 point-scale survey printed out and handed-in to seniors living in 11 Austrian senior homes. The survey has been constructed through secondary and primary data collected through problem-centred interviews with four experts (a robot researchers, a senior homes carer, a senior homes director and a town council politician) addressing general expert experience, relationship between eldercare and technology in Austria, impressions on social assistive robots and Care-O-Bot, acceptance chances. The data has been then analysed with SPSS statistical software, in particular after descriptives, Cronbach's alpha reliability test has been executed on constructs identified as possible determinant for willingness to adopt. In a second time, correlation and regression analysis have been performed, in order to identify a behavioural equation for our specific significant interest group. Such equation has been, then, adapted for including heterogeneity: the presence of different opinions has been confirmed through cluster analysis, from which the opinion dynamics model has been derived. Finally, a computer-based simulation has been run through LSD simulation software.

VI. Results

A. Decriptives and Reliability Test

Over 131 dependent-living seniors without cognitive disabilities, the 74% of the sample is represented by women and the 56% of overall respondents appears over 80 years old (the 44% between 65 and 80 years old). Moreover, half of the sample shows physical impairments. The sample has overall an average education level and, as predictable, the 63% does not own, neither use, a computer. The reliability test has been then executed and all constructs have been proven to be meaningful with a Cronbach's Alpha over 0,7.

TABLE III Cronbach's Alpha

Code	Cronbach's Alpha
ANX	0,715
ATT	0,745
PENJ	0,762
SI	0,905
TRUST_SOURCE	0,795
TRUST_MESSAGE	0,835
WOM	0,767
PU	0,786
PEOU	0,736

B. *Initial Opinions'Configuration*

First hypothesis to apply the model is that the social system under consideration is heterogeneous in believes, opinions and experiences. Furthermore, it is likely to assume the presence of extremist behaviours. In order to test this hypothesis and capture such heterogeneity, a cluster analysis has been performed on the ten drivers above mentioned (Anxiety, Perceived Enjoyment, Social Influence, Attitude towards Technology, Perceived Usefulness, Perceived Adaptability, Trust in Robot, Perceived Easiness of Use, Perceived Sociability, Social Presence). The clustering has been performed through hierarchical method in order to select their number, used then as basis for a k-means classification. The factors resulted significant for the segmentation (p-value < 0.05). From the analysis, four clusters of opinions emerge as described by clustering final centre table IV. The peculiarities of these opinions' group can be summarised as follows:

- *Enthusiast (14%):* This cluster's members perceived Care-O-Bot 4© as easy to use, useful and reliable. They have a positive attitude toward technology and are genuinely interested in Care-O-Bot 4© seen as enjoyable. They don't fear to become dependent or loose privacy, neither that the robot could make mistakes. Furthermore, they are sensible to social influence to form opinions on this topic.
- *Sceptical (51%):* This group is not confident about the reliability of a Care-O-Bot 4© and its ability to fit their needs. However, they value it as easy to use and useful overall. Furthermore, these respondents have a positive technological attitude and perceive the robot as enjoyable. Positive factor for acceptance is also the low value of anxiety.
- *Worried (23%):* This group has an instinctive negative reaction towards robot concept: fear outcomes attraction. They perceive the robot as threat for safety, privacy and independency. This technology for this group is hostile and difficult to use.
- *Against (12%):* This cluster strongly rejects the very idea of robot, which is not attractive, either interesting, or useful for them. They perceived Care-O-Bot 4© as difficult to use, have a negative attitude toward technology and hardly change their opinions according to social influence.

From the analysis, the presence of extremism is confirmed, furthermore it appears that these four groups can be related to three different initial status: the enthusiast cluster are strongly pro-SAR adoption identifiable with initial status Si=1, the against cluster which is clearly contra-SAR adoption with initial status Si=-1, sceptical and worried are instead in between the two extremist opinions and will be identified with an initial opinion Si=0.

TABLE IV CLUSTERS' FINAL CENTRE

Cluster	Sceptical	Enthusiast	Against	Worried
PEOU	0,23	1,05	-1,11	-0,55
PU	0,20	1,33	-1,44	-0,48
SI	0,15	1,46	-1,29	-0,52
ATT	0,07	1,13	-1,35	-0,11
ANX	-0,13	-0,55	-0,04	0,63
PENJ	0,27	1,31	-1,48	-0,61
TRUST	-0,02	1,35	-1,23	-0,11

C. *Opinion Dynamics*

With the purpose of determining opinion dynamics, correlation and regression analyses have been performed to identify opinion drivers and derive a possible behavioural equation (table V).

TABLE V BINARY LOGISTIC REGRESSION ON WILLINGNESS TO ACCEPT (A)

Dependent	Independent	Regression Sig. (p-value<0,05)	Regression Beta	Regression Exp. beta	Cox's R2
Willingness to Accept	PENJ	0,643	0,225	1,252	0,483
	SI	0,000	2,624	13,797	
	ATT	0,011	1,105	3,020	
	PU	0,877	0,075	0,927	
	TRUST	0,888	0,054	1,055	
	PEOU	0,533	0,213	1,237	
	Constant	0,000	-11,709	0,000	

While correlation analyses confirmed the hypothesis, binary logistic regression emphasizes only two determinant of opinion formation: social influence and personal attitude.

A multiple linear regression on these two elements allows to find their determinants (table VI).

TABLE VI MULTIPLE LINEAR REGRESSIONS ON ATT AND SI

Dependent	Independent	R2	Beta	T	Sig. (p value <0,10)
ATT	PU	0,368	0,596	2,807	0,006
	PENJ		0,250	1,341	0,102
	PEOU		0,578	2,994	0,030
	Constant		3,753	4,553	0,000
SI	Trust_Info	0,537	0, 954	7,831	0,000
	WOM		0, 523	3,432	0,001
	ANX		-0,110	-1,746	0,083
	Constant		-1,343	-0,739	0,461

As result personal Attitude toward the technology appears determined by Perceived Usefulness (as construct of reliability, usefulness and robot adaptability to users' needs), Perceived Easiness of Use and in minor degree by Perceived Enjoyment, (as construct of social presence and perceived sociability of the robot). Social Influence, instead, appears influenced by Trust in the information (as construct of trust in the content and source of information), Word of Mouth tendency, and in minor degree by Anxiety (as construct of evaluation of possible mistakes, privacy invasion, possible dependency and risk of substitution of human contact). Anxiety has a negative effect on social influence and the two variables are negatively correlated, thus meaning that a higher the anxiety, lower the chances of changing opinion about the robot. At this point, the binary logistic regression has been performed again with only the two significant factors, in order to determine a behavioural equation.

TABLE VII BINARY LOGISTIC REGRESSION ON WILLINGNESS TO ACCEPT (B)

Variables in the Equation		B	Sign.	Exp(B)
Fase 1[a]	Attitude	0,974	0,004	2,649
	SI	2,188	0,000	8,920
	Constant	-0,272	0,282	0,762

In this way, we can compute the probability of robotic adoption (P_{pro}) according to (1).

$$P_{pro} = [1/1+e^{-(-11,412+0,596SI+0,582ATT)}] \qquad (1)$$

We can better describe this equation by adding social influence and attitude determinants as described in formulas

$$SI = 0,954\ Trust\_Info + 0,523\ WOM - 0,110\ ANX \qquad (2)$$

$$Att = 0,596\ PU + 0,578\ PEOU + 0,250\ PENJ \qquad (3)$$

By adapting this equation for the average values obtained through cluster analysis, it has been possible to derive the probability that members of the two undecided clusters (sceptical and worried) would switch their opinion toward the two extremist position "pro robot" and "against robot" under social influence of neighbours belonging to enthusiast and against clusters.

By inserting the average values for social influence and personal attitude, it appears that:

- P sceptical → enthusiast= 0,53
- P sceptical → against = 0,47
- P worried → enthusiast= 0, 32
- P worried → against= 0,68

TABLE VIII RESULT OF HYPOTHESIS TEST

H1: Heterogeneity in users' opinions	Confirmed	Four different opinion cluster have been identified
H2: Social Influence and Attitude are the main determinant of Willingness to Adopt	Confirmed	The analysis confirmed the hypothesis
H3: Perceived Utility, Perceived Easiness of Use, Perceived Enjoyment, Anxiety impact on Attitude	Partially confirmed	Anxiety does not appear as a determinant of individual attitude toward SAR
H4: Trust, WOM attitude, Education	Partially confirmed	Education does not appear correlated, on the contrary ANX appears as determinant negative factor for SI: higher the fear of the technology, lower the availability to change opinion

D. *Computer-Based Simulation*

To the initial CA assumptions described in the model section, another condition has been added:

- The initial status (Si) of the agents at t0 could be of three types i.e. "1" (agents willing to adopt the robot); "0" (agents unsure if adopting the technology); "-1" (agent strongly against adopting). The number of agents for each status has been established from the data and the model set their distribution randomly. These are so called "seeds".

In order to run the simulation, it is necessary to define mathematically the mechanism beneath agent interaction. From our results, illustrated in the previous section, the rules of interaction have been set as follows:

As far as "active agents" are concerned:

- Agents with Si "1" or Si "-1" at time t0, will remain respectively with Si "1" or Si "-1" at time t1
- Both groups of agents with state Si "1" or state Si "-1" will communicate actively through WOM but the former will spread positive word of mouth (PWOM) while the latter negative (NWOM).

As far as "passive agents" are concerned

a) If the majority of their neighbours have opinion Si "1"

- The 51% of agents with Si "0" at t0, will update state in Si=1 at t1 with a probability=0,53
- The 23% of agents with Si "0" at t0, will update state in Si=1 at t1 with a probability=0,32

b) If the majority of their neighbours have opinion Si "-1"

- The 51% of agents with Si "0" at t0, will update state in Si "-1" at t1with a probability=0,32
- The 23% of agents with Si "0" at t0, will update state in Si "-1" at t1 with a probability=0,68

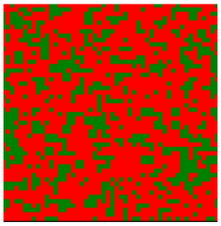
c) If the number of neighbours with opinion Si "-1" = number of neighbours with opinion Si="1"

- The 51% of agents with Si "0" at t0 will update state in Si=1 at t1 with a probability=0,53
- The 23% of agents with Si "0" at t0, will update state in Si "-1" at t1 with a probability=0,68

The model should test the result of this interaction with a simulation in many time steps. At each time step, the state of agent will be defined as function of the state of neighbours in the previous time step and the probability the agent has to adopt given its characteristics derived from the data analysis.

The simulation has been run in 1000 time-steps on a 50x50 lattice. The software used is the LSD, Laboratory for Simulation Development, based on C++. LSD is an online source for developing discrete-time simulations and specifically designed for economically oriented simulations [50].

Fig. 1. CA Simulation run on a 50x50 lattice with LSD software



As a result it is clear that the NWOM prevails by blocking the percolation of innovation and creating a strong rejection in the social system. The green dots represent agents adopting the innovation, while red rejecting. Only 32,8% of total cells are at state “1” at the final simulation step.

VII. Discussion

This study addresses innovation diffusion, by looking at a pre-market phase in which a technology is not on the market and exploring how positive but also negative WOM contributes to form a market open to the technology or against it. In particular, it looks at the acceptance of a service social assistive robot, namely Care-O-Bot 4, among seniors living dependently in Austrian retirement houses. In doing this, the work aims to link the microscopic behavior of final users with the macroscopic phenomena of adoption through cellular automata model and percolation theory. Few marketing studies take into account social percolation and fewer consider negative word of mouth effect. Still many researches are needed for validating results. From our analysis, some interesting implication comes out:

A. Research Implication:

- Percolation approach is useful in a pre-market analysis, since WOM dynamics affect the market readiness for innovation acceptance. There is still little attention to the emergent effect of consumer interaction in potential markets [16] . This paper tries to look at consumer interaction through data science and ABM for finding determinants of social influence and individual attitude able to influence the adoption and investigating how individual interaction generates macro-pattern of behavior. In this way, even if much more research is needed, this paper suggests a behavioral equation as first step to achieve a better comprehension of social dynamics and their impact on innovation diffusion.

- Negative Word of Mouth has a strong impact and prejudices on SAR innovation are able to block the innovation entrance in the market since NWOM is perceived as more informative and reliable [16] even when it is spread independently from the actual product trial like in our study. The effect of NWOM is not usually taken into account in innovation diffusion studies, however this work shows that it is a relevant obstacle to consider for preventing product failure.

B. Managerial Implication:

- Innovation acceptance/rejection is dependent from personal attitude and social influence, especially in a social context like senior homes.

- Attitude is not only influenced by Perceived Usefulness, and Perceived Easiness of Use but also by the construct Perceived Enjoyment, as the extent to which the robot is perceived “sociable”, “friendly”, “living”, “human-oriented” “caring”. This construct deals with the dimensions of social presence (meaning how much the robot has a presence thanks to its peculiar personality i.e. emotion and intelligence) and perceived sociability (meaning how much the robot is able to socially interact with the users). This dimension is arguably hardly measured in a pre-adoption analysis and needs to be further investigated through a robot prototype. However, the impact of this dimension on individual attitude, confirms the importance of social interaction skills and social intelligence in future AI developments.

- Social Influence is related to trust in message and source, the tendency to share information with the others and also to anxiety degree: higher the fear due to mistrust in the technology (possibility of mistakes), privacy issues (the robot is perceived as an invasive presence in the environment, it is seen as a guardian more then an helper), need for human contact (the robot is perceived not to aide but to substitute humans in an unethical way) lower the tendency to switch toward acceptance under social influence. On the contrary, higher the chances to switch toward rejection for negative opinion. In context of high uncertainty, like innovation introduction in the sensitive context of institutionalized eldercare settings, it is easy for NWOM to spread and block the innovation.

- The innovation does not percolate in the system because of NWOM, however, in the overall sample, heterogeneous positions and mixed feelings appear, thus opening possibility to identify a foothold market and implement strategies of entrance.

- Starting from the analysis of the four groups identified it is possible to suggest some guidelines for proper communication and positioning of the technology as summarized in the table IX.

TABLE IX POSSIBLE STRATEGIES

Cluster	Problems	Actions	
Enthusiasts	-Targeting them in the fist phase of entry -Satisfying their needs	**Communicating**: Involving experts in the robot deployment, offering assistance and group sessions in which the first adopters can share their experiences	**Positioning**: Promoting and explaining the assisting functions by underlining robots security and autonomy. **Robot development:** Working for creating products efficient before the market test
Sceptical	- Lack of trust in the robot and diffident about the conformity of the robot for satisfying their needs	**Communicating**: Working together with carer for dealing with the robot, and stimulating confrontation between them and the "enthusiasts" group members.	**Positioning:** Promoting the monitoring function by providing transparent and clear information about data storage, processing and protection in order to enhance trust and perceived adaptability. Also entertaining function is appreciated **Robot development:** Working for guaranteeing the privacy and improving technical capabilities for monitoring.
Worried	-Worried for ethical concerns, rejection of the concept of robot	**Communicating**: stimulating confrontation with other seniors, suggesting trials with carers support	**Positioning:** Promoting security and working on aesthetic design and entertaining functions for improving unconscious acceptance of robots. Strongly underlining that robots cannot substitute humans but only support them in their daily life **Robot development:** increase capabilities associated with assisting function and social skills.
Against	-Technology Rejection, robots are seen as evil machine dangerous or anyway useless	**Communicating** Opening an honest dialogue with them to better understand their opinions. Trying to stimulate their interest in technologies in general before then in robots through games, activities, workshops	**Positioning** They could access robots only when the product would have reach a technological maturity in terms of technical capabilities and so it would be extremely easy to use. Improvement in robotic aesthetic design and social presence may stimulate unconscious acceptance and promoting a better image of robots.

VIII. LIMITATIONS AND FINAL CONSIDERATIONS

Starting from social percolation and complex system theory, this research combines data science and agent-based modelling to look at opinion formation and dynamics and conduct a pre-market analysis of one of the most revolutionary and disruptive technologies of our time: social assistive robots. However, this work is not one without limitations: a larger sample would increase results' accuracy especially on regressions analysis, a demographic stratification could give more insights on the impact of demographic variables, the cellular automata model fixed structure could influence results, the absence of a real robot prototype bias perception. Nevertheless this paper value lies in suggesting an innovative approach to innovation diffusion modelling.

To this purpose, influential drivers of social assistive robots acceptance have been selected from the literature and investigated through statements rated by dependent-living seniors on a five-point likert-scale. As result, a cluster analysis allows to underline respondents' heterogeneous opinions. In this way, two extremist clusters, enthusiast and against, and two moderate clusters, sceptical and worried, emerge. From this starting point, opinions initial configuration has been set. A regression analysis, then, has emphasized the role of two drivers, social influence (dependent on trust message, source of information and attitude to share word of mouth) and personal attitude (dependent on perceived enjoyment, perceived adaptability and perceived easiness of use) on innovation acceptance. From this consideration an equation has been defined with the purpose to derive probabilities of opinions' change for the two moderate clusters and run, so, a computer-based simulation.

As result social assistive innovation success appears threated by the strength of negative opinions, mainly due to physical, psychological, ethical and social barriers, that SAR needs to overcome for achieving success. The study of social impact dynamics and the correspondence between users needs and robot abilities and the proper communication of the new technology appear as key factor for social assistive robots future.

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