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Connected objects: Economic modelling of time arbitrage

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Abstract

The aim of this article is to propose a general analytical framework that can be transposed to different experiments and studies about individual preferences for connected objects (CO) at home. From revealed individual preferences for CO over time, as a substitute for non-connected time, we formalise a simple microeconomic optimisation model applied to two individuals assumed to share the same home. We show that individual preferences naturally seek a balance between time passed on CO, social link with the housemate and time devoted to other activities.

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1. Introduction

The presence of connected objects (CO) in our daily lives is booming. Reinforced by successive lockdowns related to the Covid-19 pandemic and teleworking, the trend has gone upwards. More generally, in addition to smartphones, connected televisions, tablets and computers - which already have a strong presence in households - CO are continuing to spread throughout our society (connected mirror, smart floor, smart fridge, smart security, etc.). Health-related COs are the most widespread (24% in France, according to the digital barometer (ARCEP, 2022)), but the most spectacular increase concerns security-related COs (21%, +7 points between 2020 and 2022). The global end-user market for connected objects reached the size of 212 billion US dollars at the end of 2019, and forecasts suggest that the sector's commercial revenues should reach around 1.6 trillion by 2025 (Statista, 2021). In 2030, the highest number of IoT devices will be found in China with around 8 billion consumer devices (Statista, 2023). These objects are now colonising our homes, changing household behaviour, and transforming human relationships. By profoundly modifying home interaction patterns, CO - and by the same token NICTs (new information and communication technologies) - are overturning the construction of territories, from busiest neighbourhoods to most rural areas (Genre-Grandpierre and Lacour, 2023).

The aim of our study is to examine the role of CO in our habitats and their effects on human and social interactions. Thus, as a part of this work, we are interested in evaluating the optimal individual and collective utility for CO, by proposing an economic approach aimed at measuring the willingness of individuals to consume CO, assuming that individuals seek their utility through economic choices.

In what follow, we present a general framework for our analysis that can be exported to different experiences, based on modelling individual preferences for CO. Given that the aim of this article is to propose a toolbox that can be used in different contexts, the question of the pricing of CO is not addressed. Therefore, the willingness to consume CO is approached here through a 'willingness to spend time' on CO rather than a 'willingness to pay' for CO. We assume that the more individuals devote their time to the use of CO, the more they prefer CO over other activities and the more they would be prepared to pay for them. However, it is important to point out that many studies converge in explaining that consumption and dependency even, is partly determined by supply (marketing, etc.) and that economic agents are therefore under influence (through socialisation, advertising, etc.).

Individual utility is therefore approached through the time trade-off between several activities. Consideration of collective utility and recommendations in terms of public policy involve asking questions about the social time spent on CO, and proposing health, environmental or ethical standards to differentiate CO, limit their use or, conversely, propose new ones. Our research question is twofold:

(1) What are the links between digital activities and social activities carried out at home, and the individual utility that is derived in each case?
(2) What effect might policy recommendations have on habits in terms of CO use?

The aim of this research is to analyse the effects of the increasing digitisation of our society, and its benefits and risks in the context of social interaction.

First, we will review the literature on connected objects and the effect of connection time on people's wellbeing. In the second part, we will propose a microeconomic model of time arbitrage applied to two inhabitants sharing the same home (for example two flatmates or housemates or a couple). According to INSEE[1] (2021), the average household in France is made up of 2.2 people, so although more than a third of households are made up of a single person, and barely a third of households are made up of two people, we felt that it would be more appropriate to address our research question considering a two-persons household. We then conclude in a third section.

2. Literature review

2.1. Connected objects

CO can be defined as objects that capture, store, process and transmit data, that can receive and give instructions and that can connect to an information network. A broader definition of the term is suggested by Zhong (2019): "a connected object is a physical object equipped with sensors and processes to which the addition of a network connection makes it possible to offer new services to transcend its initial use." This network is known as the Internet of Things (IoT). This network is known as the Internet of Things (IoT). There is a wealth of literature on this subject, including the work of Hoffman and Novak (2018) and Novak and Hoffman (2019). Lu et al. (2018) review the relevant business literature from the user and organisational perspectives business related to the Internet of Things. The authors recommend that companies make efforts in data protection, which is one of the major concerns of users.

The connected home is not just the sum of several CO, but a dynamic ecosystem based on a digital information distribution network, with varying degrees of autonomy, i.e., with or without direct action by users, with or without commands from users, and with or without *artificial intelligence,* making these objects capable of learning for themselves by taking decisions on behalf of individuals. Arruabarrena (2022) identifies three overlapping phases in the history of CO: during the 1990s and until the early 2000s, the evolution of CO focused on infrastructures and the networking of CO; then from the 2010s, where we saw "the convergence of CO with artificial intelligence and megadata"; which led to a strong growth of CO in different business sectors, notably in energy networks (Morvan, 2021) and healthcare (Cambon, 2016).

As noted by Arbelet et al. (2017), consumer behaviour towards CO varies. Indeed, agents may experience difficulties of use at first, as CO just enter the market, while others CO meet users' needs with almost instant success. In sport, for example, the number of people using CO and mobile applications is growing (Soulé, 2022). To be of real value to a wide audience, CO need to be integrated into everyday life (Zhong and Balagué, 2021). In this vein, Sandström et al.

[1] INSEE (Institut national de la statistique et des études économiques) is the French national institute of statistics and economic studies.

(2008) explain that the value attributed to CO depends more on the user experience than on the service capacity itself. Attié and Mayer-Waarden (2022) explain the acceptance and usage of CO. They show that utilitarian benefits are the main reasons leading to CO technology acceptance, and well-being and social image lead to higher usage in the long term. Although there is a meta-analysis on the acceptance and use of CO technology (Blut et al., 2021) the authors point out that "there is a gap in the innovation literature to explain users' perceptions, motivations and barriers to using smart CO technologies" (p.2).

Also, in the context of smart homes, Folcher and Mussol (2018) consider that interconnected objects could influence the comfort of residents according to the theory of arrangement - which assumes that objects acquire greater value once they are connected. This idea has already been addressed in the literature by Robles and Kim (2010), who stress that all the devices in a smart home should be connected: radiators, windows, televisions, etc. While it is now clear that CO interact with the Internet (Poslad, 2009), surveys results show that the underlying application must be user friendly first and foremost to be successful. For Waleed et al. (2018), the simplicity of use of CO takes precedence over their accuracy. For example, Raducanu (2020) has shown that agents are not necessarily looking for an original innovation, but rather for near-perfect functionality. Balta-Ozkan et al. (2013) emphasize the importance of barriers such as loss of control, security and cost, in the implementation of smart homes.

Zhong and Balagué (2021) review three main categories of CO taxonomy from the literature: a technology-centric taxonomy (the object is seen as a 'technological entity'); a user-centric taxonomy (the relationship between the object and the user) along the lines of Smutny's (2016) work; and a neutral taxonomy (the object is defined in terms of its purpose and creator: for commercial or personal use). Observing that "the technology-centric taxonomy remains predominant" in the literature, the authors propose a more transversal separation of CO: CO as designed; CO as co-created; and CO as self-created.

Finally, for the sake of simplicity, we propose to group CO into two categories: CO that can replace the action of human beings on the one hand, with special settings or artificial intelligence that perform actions (cleaning, ordering, alerting, etc.); and CO that require an interaction with the individual on the other hand, and therefore time, in order to inform, entertain or guide the individual according to the options that he or she has activated (e.g. smartphone, smart mirror, intelligent personal assistant such as Alexa, etc.). For the remainder of this article, we focus exclusively on this second category of CO, as these can be controlled by the individual, and not just at the level of initial configuration.

2.2 Effect of connection time on wellbeing

Screen time has an ambiguous effect on wellbeing[2], with authors Lavoie and Zheng (2023) differentiating, for example, between the use of so-called productive applications (email, notes, etc.) and other applications available on mobile phone (social networks, etc.). Under-24 years old show a positive and uniform effect on wellbeing, measured by the 'flow' or the feeling of being in full possession of one's resources without effort, when using productive applications;

[2] The notion of wellbeing here refers to the definition most accepted among psychologists, namely that of subjective wellbeing, which considers that positive emotions perceived by an individual are stronger than negative emotions.

while older age groups tend to show a drop in the same 'flow' as the time spent on screens increases. Conversely, the authors observed that time spent on so-called entertaining applications brought greater wellbeing to the older age groups than to the under-24s.

One of the major adverse effects on wellbeing resulting from the use of CO and screen time notably, is the acceleration of sedentary lifestyles, with repercussions on people's psychological health. Research on cohort data tracking the physical activity of 4,526 46-year-old English people in 1970, 2016 and 2018 conducted by Nipuna et al (2021) shows that low levels of physical activity (mostly sitting) could be associated with lower levels of psychological health, as measured by the 14 reference items of the Warwick-Edinburg Mental Wellbeing Scale (WEMWBS), irrespective of gender, physical condition and other socio-psycho-demographic criteria. On the same subject, the meta-analysis by Almourad et al (2021) identifies the negative effects of excessive and compulsive telephone use on the emotional state, social interactions, and job satisfaction of users, highlighting in particular the increase of anxiety, depression, insomnia and the feeling of loss of productivity. Chouk and Mani (2016) add to these factors impacting users' welfare those of mistrust and resistance towards CO, notably due to their complexity and perceived risks in terms of privacy and discrimination.

3. Microeconomic approach to preferences for connected objects

3.1. Time arbitrage model applied to two individuals in a shared habitat

To study individual preferences for CO, we propose at this stage a simple model of time arbitration between three alternatives: individual time spent connected on CO, on social time with another individual (connected or not), and time disconnected. We hypothesise that the 'time' variable reflects the willingness of each of the two cohabitants (let's assume a couple or two flatmates or housemates, for example) to prefer one activity over the other, given that some are irreducible or constrained (sleeping, eating, shopping, but also answering the phone, etc.). The longer a cohabitant uses a CO, the more he or she will be considered to prefer that CO to another occupation, whether alone or with the other cohabitant. The connected objects that are considered in our model are those that essentially hold an individual use and that are not directly associated to a domestic activity – such as smartphones, connected bikes, connected mirrors, etc. The amount of time spent on CO is therefore indicative of their willingness to use them. Conversely, the time spent by the two individuals being together is considered as 'social time'. Finally, time spent by one individual being both disconnected from the CO and distanced from the other individual is considered as ‘unconnected’ activity (study time, sleep time, reading from unconnected objects, but also social time spent outside with other people than the cohabitant, etc.).

The aim of this model is to find out whether connected objects - and in particular connected objects for individual use - can create barriers in human relationships, and particularly within homes made up of two "cohabitants". In addition, the idea is also to enable analysis of the relationship that individuals have with COs in general.

According to the model we propose here, the two individuals therefore reveal their respective preferences by optimising a weighted equation between the utility derived from consuming CO, the utility of the relationship with the second individual and the utility of all their other (non-connected) activities, under the constraint that they cannot allocate their time to all these activities at once. The three activities are assumed to not be concurrent. The trade-off in allocating the daily time constraint (T=24 hours) between all the activities that each of the two individuals prefers is expressed as the maximisation of the function of the time constraint, as follow:

$$Max\ U_i\,(x_1\,, x_2\,\ldots, x_n) = t_1\,u_{i1}(x_1) + t_2\,u_{i2}(x_2) + \cdots + t_n\,u_{in}(x_n) \qquad (1)$$

Under duress $\sum t_\theta = 1$

We can write the utility function for each inhabitant (i and j) :

$$U_i\left(x_i, y_i, z_{i,j}\right) = t_i\,u_{i1}(x_i) + (1 - t_i)(\,\alpha_i\,u_{i2}(z_{i,j}) + (1 - \alpha_i\,)\,u_{i3}(y_i)) \quad (2)$$

$$U_j\left(x_j, y_j, z_{i,j}\right) = t_j\,u_{j1}(x_j) + \left(1 - t_j\right)(\,\alpha_j\,u_{j2}(z_{i,j}) + \left(1 - \alpha_j\right)u_{j3}(y_j)) \quad (3)$$

As the social interaction time must be shared, this optimisation takes place under the following constraint:

$$(1 - t_i\,)\,\alpha_i\, = \left(1 - t_j\right)\alpha_j \qquad (4)$$

- i, j denotes the two individuals
- x_i and x_j represent the use of CO by i and j
- y_i and y_j represent the activities of i and j excluding connected objects and interactions between i and j
- $z_{i,j}$ represents the social relationship between the two individuals
- t: time coefficient allocated to CO, $0 \leq t \leq 1$ (T = 24 hours)
- α : socialisation coefficient characterising the time spent with the other $0 \leq \alpha \leq 1$

Note: *y* and *z* are distinguished here but represent activities during which individuals do not use any CO.

This model allows us to look at the distribution of time in each resident's day, between the three alternative occupations: connected time, social time together and time devoted to other activities, and the rebalancing effects between each of these three activities[3].

3.2 Elasticity of substitution and deformation of intrinsic preferences

Using the proposed model, we can experimentally calculate connection times, social times, and other timed activities on an individual or collective scale (experiment within a connected flat/home), and the variation in such time allocations as a function of the number of connected

[3] For the sake of simplicity, we assume here that users do not consider the issue of data collection.

objects present at home. We can determine whether a substitution effect exists between CO, and test:

- the impact of connected time on social time;
- the impact of an increase in relational time between individuals on individual connection times.

In other words, the elasticity of substitution between social utility and digital appetite.

- The increase in other activities (time alone, time away) and their impact on connection and social time.

These questions can be addressed by means of marginal rates of substitution between the three 'goods': 'connection' (x), 'disconnection' (y) and 'socialisation' (z).

We can also look at the shape of personal utility functions and the ways in which they change as CO are introduced or as one activity takes over the other. We could look at:

- The convexity of preferences, in the case where individuals would prefer a mixture of connection (x) and non-connection (y + z) rather than only connection (x) or only non-connection (y + z).
- the monotony of preferences, insofar as individuals could reach saturation and demonstrate a negative marginal utility for the connection or for the social relationship.
- the ordinality of preferences and their translation into temporality, in other words whether the time spent on one activity reflects the individual's intrinsic preference, or whether phenomena of colonisation or cannibalisation of one activity over the other appear. The preferences revealed by the amount of time spent on each activity may in fact reveal distortions in relation to the initial preferences assumed to be intrinsic, for example because of habituation or re-balancing of preferences following a change in the individual's behaviour.

4. Conclusion

After reviewing the literature on CO and smart homes, we proposed an approach to individual preferences using a model of time arbitration between connection, socialisation and non-connection. The modelling of the willingness to use connected objects that we have proposed is original in that it formalises time as a currency of exchange, questioning the uses of CO from an economic point of view. Behind the hypothesis that 'time is money', this approach seeks more to define the preferences that individuals will reveal for CO through their daily schedule of activities, than to test the budget elasticity that individuals would be prepared to spend to buy a particular CO. The microeconomic model of temporal arbitrage should make it possible to test, at the level of individuals sharing a common environment, the substitution effects between connected time and social time, and possibly identify threshold for habituation, colonisation or cannibalisation effects of one activity over another.

This raises other questions that our article does not answer at this point. Should other nudges be introduced to regulate the digitalisation of society? Should the wellbeing that CO seem to provide be left to the discretion of each individual, even if this means that the distortion of preferences resulting from the use of CO may lead to a neglect of social ties or other socially preferable activities? In other words, before embarking on a large-scale connected habitat, should the scientific community characterise what is expected of a CO and its impact on our lifestyles, both individually and collectively?

CO can represent an opportunity in terms of wellbeing, with the development of devices to save energy, improve our comfort, facilitate decision-making with information from intelligent networks, or present a risk factor that should not be overlooked if the omnipresence of CO were to deviate from intrinsic preferences in favour of greater disconnection or non-virtualised relationships.

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