The Value of Smart Home Features in the Brazilian context

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Abstract. The conversion of conventional household products and services into smart alternatives has emphasized the utilization of technologies that facilitate communication between devices and other systems. Despite the numerous benefits that various smart home functionalities offer to users in their daily lives, recent research has shown that certain solutions can diminish the perceived value of the overall system. This article presents a decision-making tool aimed at assisting practitioners in evaluating the economic value of different smart home features. A model, estimated based on a sample of 255 respondents from the southern region of Brazil, indicates the Willingness to Pay for each smart home feature. The findings reveal that safety devices and household resource meters are the features for which Brazilian customers exhibit the highest willingness to pay, highlighting an opportunity to integrate these solutions into new home designs

Keywords: Intelligent Home, Stated Preference, Willingness to Pay, Internet of Things, Survey.

1 Introduction

The term smart is often associated with technological innovations [1]. The transformation of traditional products and services into smart ones has triggered the use of technologies that allow communication between devices and other systems [2]. In the household, the technologies embodying the smart home concept refer to devices that provide some degree of enhanced or digitally connected services [3]. Smart homes have become central theme in recent discussions on technology and politics involving energy efficiency, climate change, and innovation [4]. Technological solutions applied to smart homes have reached new markets, either by increasing the availability of digital resources [5] or by improving dwellers comfort and quality of life [6].

Among the concepts for a smart home is the one that presents it as a home equipped with a high-tech network, connecting sensors, household devices, appliances, and resources that can be monitored, accessed, or controlled and provide services that respond to the needs of their inhabitants [7]. It emphasizes technology as the smart home's main feature, which can meet the user's needs through this technology. However, technology-focused- smart-home is being updated by a more integrated view focused on the services provided to users. This updated version refers to the smart home as the integration of intelligent devices and sensors into a smart system, which provides users with services that allow them to have access to a whole range of economic, social, health, emotional, sustainability, and safety benefits [1].

Despite the benefits of many smart home functionalities to user’s daily life, recent research depicted that some smart home solutions can undermine the value perception of the system. The case of windows that open and close automatically to enhance thermal comfort [8] or even the gas consumption monitoring to users who live in houses [9, 10] that undermine the user’s perception of value of the smart home system. The literature presents the value perception of some smart home features, such as home automation [11] and smart meters [12]. However, the literature still needs to clarify an evaluation of the customer's value perception of smart home features in an integrated view. Thus, this article provides a decision-making tool for practitioners to assess the economic value of several smart home features simultaneously.

2 Literature Review

The smart home is a broad and relevant research topic, with different subjects, research gaps, and emerging benefits, but also with challenges for all smart home players, including providers and customers [5]. Many residential automation solutions tend to be incorporated into house building [13]. Over time, all homes will have some kind of automation, such as temperature monitoring items, lighting, air humidity [14], windows that open and close automaticaly [15], security systems [16], alarm management items, schedules, lighting [15], comfort items, integration of appliances [17] and for thermal comfort purposes [18]. The integration of these types of automation configures the connection network necessary to characterize a smart home concept [1].

The bulk of the literature on the smart home is focused on the technologies that embody smart home solutions [19–22], or some specific aspects of the technology applied to particular solution, such as energy systems [23, 24] or health care [25, 26]. The remainder of the literature, which is more recent, analyzes the smart home from the user's perspective [27, 28]. From this perspective, few theoretical research about smart homes discusses its benefits [29], barriers [7, 11, 30] and services [31], or investigate the factors that influence the acceptance of the smart home solutions by users [32]. Thus, the literature focused on the user's acceptance of smart home technologies is a recent and developing theme, which allows unfolding in various areas of science, including engineering.

3 Theoretical Development/Model

3.1 The smart home features and the questionnaire

Several authors present smart house features, such as routine automation [7, 33], remote management [19], entertainment [34], energy management [35, 36], security [37, 38], Health Care [15, 25], among other features. The research prioritized six smart home features based on the previous literature as well as the most available smart home features on the market: (*i*) household appliances, (*ii*) smart illumination, (*iii*) air conditioner/HVAC, (*iv*) security system, (*v*) smart resource meter, (*vi*) tv and stereo system, and (*vii*) automatic window opener and closer system. The building of the questionnaire utilized the combination of the six smart home features plus the price to create the scenarios using the Design of Experiments approach. The scenarios were built using a fractional factorial design ($2^{(8-3)}$), resulting in 32 different scenarios presented to the respondent in eight choice tasks with four different scenarios each. Figure 1 presents an example of a choice set presented in the questionnaire.

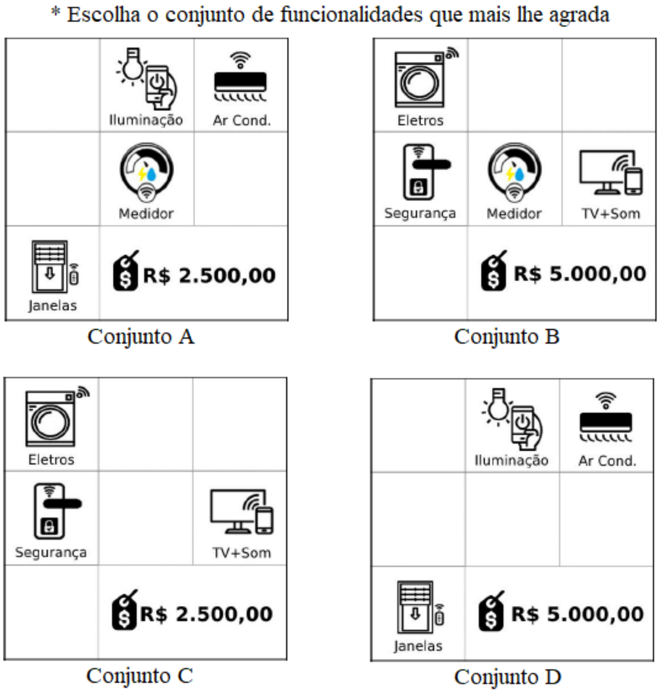

Fig. 1. A choice set of the questionnaire.

3.2 The model estimation

This research employs the stated preference technique to estimate the model's parameters and gain insights into customer behavior when considering the adoption of smart home technologies. The stated preference technique has been widely used in the literature to estimate models for other devices, such as smart meters [10, 39], semi-automated home systems [11], and smart vehicle assistants [40]. In the stated preference technique, respondents are not given the option to choose the level of each attribute individually. Instead, they are presented with specific scenarios containing a combination of attributes, and their task is to select the best combination [41]. These scenarios are presented in sets of choices, known as choice tasks, which display the attributes that represent the system [42].

The literature recommends using the Conditional Logit Multinomial Model (MLM) to analyze the choice task data. This model considers that the same respondent performs multiple-choice tasks, and the selection of a specific scenario is conditioned on the alternatives presented. In this study, the MLM is a specific case of the choice model proposed by McFadden [42]. The Willingness to Pay (WTP) represents the marginal value of each functionality, and its estimation is obtained using Equation 1. The WTP estimation involves the coefficients β_N for non-monetary variables and β_M for the monetary variable [42]. Confidence intervals for WTP values were calculated using the Krinsky-Robb method [43]. This method provides an alternative approach to simulate the asymptotic properties of the estimated parameters based on maximum likelihood estimation. It allows for the generation of simulated standard errors and covariances of the estimated parameters, assuming a multivariate normal distribution [44].

$$WTP = \frac{\partial V / \partial V_N}{\partial V / \partial V_M} = \frac{\beta_N}{\beta_M} \qquad (1)$$

Brazil, a country in South America, is considered an emerging economy. With approximately 200 million inhabitants [45], Brazil has different regions with different infrastructures, weather, and human development indexes [46]. In order to reach more homogeneity of respondents, they were restricted to southern Brazil. In total, the sample considered 255 answers as valid. The sample is considered non-probabilistic [47]. However, it presents similarities in several characteristics to the population [45] (Table 1).

Table 1. Sample characteristics.

Sociodemographic data	Sample		Census (IBGE,2010)
Age	N	%	%
15 to 34 years old	128	50.20	45.40
35 to 54 years old	93	36.47	36.46
55 years old or more	34	13.33	18.14
Gender		%	%
Female	131	51.37	51.40
Male	124	48.63	48.60
Type of Home		%	%
House	117	45.88	81.67
Apartment	138	54.12	18.33
Number of bedrooms			
1 bedroom	26	10.20	22.36
2 bedroom	82	32.16	40.63
3 bedroom	118	46.27	31.60
4 bedroom or more	29	11.37	5.41

3.3 Method Bias

The literature highlights the importance of controlling the impact of measurement methods in behavioral research [48] as they can introduce significant measurement errors [48, 49]. In constructing the questionnaire, various procedural recommendations were considered [48]. These included using items with different scales, incorporating both positive and negative items, and ensuring respondent anonymity. Additionally, certain measures were implemented during the questionnaire administration to mitigate method bias. This involved testing different application modes (online/face) and sampling respondents at different time waves (early/late). The T-Test and Levene test were conducted, which did not reveal any significant differences in means and variances between the online/face and early/late respondent groups. Common Method Bias can be assessed using statistical procedures such as Harman's single factor and the Unmeasured Latent Method Construct [48, 50]. In the dataset, Harman's single-factor analysis extracted only 23.4% of the variance, which is below the 50% threshold suggested in the literature [50, 51]. The Unmeasured Latent Method Construct analysis indicated that only 1.74% of the variance in the database could be attributed to the method, also below the 4% threshold recommended by previous studies [52, 53]. The database assessment suggests that Common Method Bias is not a significant concern and does not undermine the reliability of the estimations.

4 Results

Table 2 displays the conditional multinomial model estimated for the smart home features. A specifics packages in the R® statistical application estimated the model. In addition to the smart home features, the term ASC (Alternative Specific Constant) was also included, consisting of a parameter not associated with any measured attributes. ASC indicates the effect of factors not observed on the choice decisions [42].

Table 2. Conditional Logistic Model estimated (MacFadden Model)

Smart Home Features	Coef.	EXP	SE	Z	p-value
ASC	-0.158	0.854	0.026	-6.123	0.000***
F1- Household Appliances	0.538	1.712	0.060	8.923	0.000***
F2- Smart Illumination	0.565	1.760	0.061	9.256	0.000***
F3- Air Conditioner/HVAC	0.419	1.520	0.060	6.975	0.000***
F4- Security System	0.910	2.485	0.058	15.638	0.000***
F5- Smart Resource Meter	0.669	1.952	0.052	12.853	0.000***
F6- TV and Stereo System	0.660	1.935	0.057	11.515	0.000***
F7- Automatic Window System	0.149	1.161	0.059	2.530	0.011**
F8-Price (R$)	-0.000	-1.000	0.000	-14.439	0.000***
Model Adjustment					
AIC	4,342.008				
BIC	4,392.550				
R^2	0.232				
R^2 adjusted	0.229				

*Significant at 10%; **Significant at 5%; ***Significant at 1%

The analysis of the conditional multinomial model reveals that all six smart home features and the price are statistically significant. Among the features, the safety feature (F4) exhibits the highest coefficient, with a value of $\beta = 0.910$ (p-value < 0.01). The Exp(coef) value represents the odds ratio associated with the feature. In this case, scenarios that include the safety feature are 2.485 times more likely to be chosen than scenarios without it. On the other hand, the availability of automatic windows opener and closer (F7) has the smallest coefficient, with a value of $\beta = 0.149$ (p-value = 0.011) and the lowest odds ratio. Table 3 presents each smart home feature's Willingness to Pay (WTP) values. The MWTP values indicate the average values in the analyzed sample, while the 2.5% and 97.5% values represent the WTP estimates for the 2.5th and 97.5th percentiles of the estimated population.

Table 2. Willingness to Pay estimations for Smart Home features

Smart Home Features	MWTP	2.50%	97.50%
F1- Household Appliances	R$1.806.80	R$1.360.10	R$2.333.90
F2- Smart Illumination	R$1.899.40	R$1.457.70	R$2.421.20
F3- Air Conditioner/HVAC	R$1.407.30	R$969.80	R$1.915.10
F4- Security System	R$3.059.30	R$2.532.30	R$3.706.10
F5- Smart Resource Meter	R$2.247.60	R$1.831.00	R$2.729.70
F6- TV and Stereo System	R$2.217.90	R$1.762.10	R$2.767.00
F7- Automatic Window System	R$501.70	R$108.30	R$910.10

5 Discussion and Conclusions

This study makes a significant contribution to the existing literature on smart home features by employing a survey-based approach and analyzing six specific features along with their associated prices. While previous studies have predominantly relied on theoretical frameworks [1, 29, 33] or qualitative methods [54], this research fills a gap by utilizing the stated preference approach to examine the integrated impact of these features comprehensively. This study provides valuable insights into customer perceptions of their value by estimating utility and willingness to pay for each smart home feature. These insights can inform the development and dissemination of smart home technologies in Brazil, enabling builders to incorporate these features into new home designs. The Willingness to Pay values obtained for each feature can also be used as an essential indicator for integrating these features into new home designs, facilitating business strategies to enhance customer satisfaction and promote wider adoption of smart home technologies.

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