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Thesis

Bandwagon and Snob effects: A Model of observable consumer behavior.

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Abstract

The independence of preferences, normally assumed in consumer theory, is rather problematic when it comes to explaining observable consumer behavior. One of the most notorious cases is when the desire for status affects the purchasing decision of consumers; this can be seen in Leibenstein's Bandwagon and Snob effects. Here I present and simulate a dynamic model of interdependent preferences for an economy of two representative consumers with different income levels and two goods, of which one provides status. I start from the demand functions derived from a member of the Bergson Family of utility functions, and non-linear adjustment formulas based on the Bandwagon and Snob effects that modify the weights in the utility function period by period. The results of the Python simulation suggest convergence to specific optimal demands for the goods: the low-income consumer ends up sacrificing part of his/her consumption of the market basket to purchase the status good and the high-income consumer reduces his/her status driven consumption.

1 Introduction

Many of the assumptions normally used in the mainstream economics models have been widely criticized. In various cases one of the main concerns of economists nowadays refers to the degree of realism of these assumptions, and how to restate them so they fit better with the observable economic agents' behavior. In respect to the pillars of the consumer theory an example of this is given by preferences that are commonly assumed as given and independent from the ones of other consumers, and thus, immutable. But the reality is that preferences seem to be endogenous to the market outcomes. The awareness of the problem that endogenous preferences constitute was present even when Alfred Marshall constructed the grounds of neoclassical consumer theory, but was ignored to guarantee simplicity (Leibenstein, 1950).

One way in which preferences can be endogenous to the market equilibrium is when they are interdependent between consumers[1], as it was presented by Pollak (1976). That is to say; individuals consume the same goods as the other members of the social class they belong, or even try to surpass their own class by copying the consumption habits of the individuals they perceive as having a higher reputation status than themselves (Veblen, 1899).

Going to daily life examples, is valid to think that when clustered by a common taste and social class, consumers buy the same kinds of goods. For example, when it comes to sportswear, many high/medium-income consumers buy Adidas and Nike, or when it comes to cell phones Samsung and Apple. But there are also cases when consumers buy goods that are clearly not meant for them. In South America, you get to see many houses built with cheap wood planks and metal roof tiles where big families live. But regardless of their condition, they still have big televisions and pay for satellite providers[2].

Consumption patterns, as the ones just presented, give a reason to define more realistic assumptions about what drives the purchasing decisions of

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[1]Other ways in which endogenous preferences have been analyzed and that I will abstract from in this thesis are: by non additive demand functions (Pigou, 1913) or by the effect of institutions (Bowles, 1998).

[2]Mota (2015) presents an opinion column in a Mexican financial diary highlighting the existence of this kind of consumer behavior in his country. In Appendix A other graphical examples can be found.

consumers. This kind of behavior could be explained better under the hypothesis of endogenous preferences than under the old-fashioned assumptions of neoclassical consumer theory. Thus, if preferences are not given, independent and immutable, the way of getting to a market equilibrium must be reestablished.

These interpersonal effects on the consumers' demands were first classified by Leibenstein (1950). He examined three different effects:1) *"Bandwagons"*, referring to the case when others' consumption boosts own consumption. Bandwagons are associated either with the desire to be stylish (Leibenstein, 1950), goods for which the utility depend on the joint consumption by others, or goods for which others' consumption generates positive externalities due to more available services and accessories[3] (Granovetter & Soong, 1986); 2) *"Snobs"*, referring to the case when others' consumption reduces own consumption. Snobs are associated with the desire for exclusivity; and 3) *"Veblen"*, for the case when a high price is the determinant of a conspicuous consumption[4] (Leibenstein, 1950).

Even if Leibenstein's contribution was a big step for the theory of interdependent preferences, there is still a gap in the literature regarding the way of representing these endogeneities in microeconomic models of consumer theory. Given all this, by following a similar scheme as the one presented by Pollak (1976), I intend to represent observable consumer behavior by means of the Bandwagon and Snob effects, specifically, the case when consumers buy goods that are not meant for their income group. Consequently, the purpose of this thesis will be to answer the following research question: How can Bandwagons and Snobs be mathematized and included in consumer the-

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[3]As presented by Granovetter and Soong (1986), when it comes to utility depending on joint consumption, restaurants are the best example. A partially full restaurant will always look more appealing than an empty one of the same characteristics. In this case others' consumption is used by people as a proxy of quality and the consumption of the service is boosted by the consumption of the same service by others. An example of positive externalities generated by others' consumption is the bigger availability of technical services and accessories for a good when its consumption increase, for example if many consumers buy the same kind of cell phone there will be more accessories or applications available for it in the market, in this case others' consumption cause an externality that can boost the consumption of other individuals.

[4]Conspicuous consumption refers to the case when individuals buy highly observable goods with the only desire of displaying wealth, this idea was presented by Veblen (1899).

ory to find a market equilibrium that explains observable consumer behavior?

To answer this question, I established a dynamic model with two representative consumers and two goods. The Bandwagon and Snob effects were included in the adjustment equations of the model. Finally, to get an insight of the existence of an equilibrium I ran a Python simulation. As expected, the results suggest modifications from the initial optimal demanded amounts for both kinds of consumers. Furthermore, the final demand converges to certain values, this implies the existence of an equilibrium after running the model for 15 periods[5].

Finally, this thesis is organized in the following way: Section 2 presents the literature background on this topic. In section 3 I develop the model and present the equations used. In section 4 I run the Python simulation of the model and show the numerical convergence of it, given specific parameter values. In Section 5 I discuss the implications of the results.

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[5]Given the values of the parameters used to run the simulation presented in this thesis. Under a different specification the periods needed to deduce convergence will vary.

2 Literature Review

The literature that explicitly focuses on Bandwagons, Snobs and their mathematization and further inclusion on consumer theory is quite limited, as was implied in the introduction. Therefore, the goal of this chapter is to present the antecedents of the Bandwagon and Snob effects concepts. Followed by the ways in which these endogeneities have been mathematically approached and included in consumer theory.

As it was mentioned before, in respect to economics, the first contribution to the theorization of interdependent preferences is usually attributed to Veblen (1899). He develops the idea of a consumption highly determined by the emulation of the expenditure of the social classes perceived to have higher status. He argued that the emulation is caused by an invidious comparison and the desire to attain honor and distinction[6]. This emulation behavior shapes consumers' tastes in a way that favors goods defined as expensive, due to their low intrinsic serviceability (Veblen, 1899).

Additionally, Veblen also suggests that even for the poorer classes the emulation is present. Therefore, physical wants are not the only thing that drives the consumption patterns of this class. The latter statement can be corroborated with more recent empirical studies like Subramanian and Deaton (1996), where it is shown that under an income shock the very poor increase their consumption of food way less than the theoretical prediction. Furthermore, these authors also show that the calories consumed increase in an even lower proportion, this because the consumers prefer to buy better quality products than larger quantities.

Following the time line, the next author who contributed to the literature of interdependent preferences was Pigou (1913). His analysis focused on the non-additivity of demand curves given the endogeneity of preferences. He was followed by Duesenberry, who in 1949 tried to reconcile the existence of endogenous preferences with macroeconomic theory in a highly mathematical way as was mentioned by Ackley (1951) in a review of Duesenberry's

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[6]Although, it must be clarified that the idea of consumers' behavior being affected by emulation and comparison existed in economic literature way before Veblen. These ideas were already present back in the works of classical authors as Adam Smith and J. S. Mill, and many others before Veblen. Several examples can be found in (Drakopoulos, 2016).

work. In Kastanakis and Balabanis (2012) we also find that Duesenberry explains how comparison and emulation based on *"demonstration effects"* of a reference group influence households' consumption decisions[7] .

Leibenstein (1950) came later to conceptualize some types of interdependent preferences under the three categories. In this thesis, I will focus on two of them. The Bandwagon and Snob effects. Furthermore, under the identification of these effects, Leibenstein took up the problem of non-additivity of individual demand functions presented by Pigou. He addressed this problem in a static way assuming that the consumers have perfect information about market conditions (Leibenstein, 1950). The proposed solution was presented by him as a graphical analysis of demand curves.

A common characteristic implied or explicitly stated by all authors mentioned until now is that the emulation of consumption is based on a reference group to which each consumer wants to belong. This idea is supported by Bearden and Etzel (1982). These authors presented an empirical study in the field of sociology that reports that individuals do not behave as their recognized peers[8]. Instead, the stimuli for creating a selective demand comes from reference groups they associate themselves with (Bearden & Etzel, 1982).

In respect to mathematical approaches to represent interdependent preferences Pollak (1976) presents the first contribution. Pollak constructed a model of interdependent preferences based on the demand functions derived from generalizations of utility functions belonging to the *"Bergson family"* (Burk (Bergson), 1936), and a scheme of necessary consumption quantities of a good, subject to interdependent preferences. The endogeneity is presented as a linear dependence on others' past consumption of the same good[9]. That is to say, interdependent preferences are represented as a modification period by period, based on the past consumption of others, of a parameter in the

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[7]According to Ackley (1951), Duesenberry's analysis is also extended to welfare economics. Arguing that income redistribution towards equality may not cause an incentives problem when the frequency of contact with the status goods, as a determinant of utility is assumed.

[8]As peers Bearden and Etzel (1982) consider people with similar backgrounds, as social class or education level.

[9]Due to this characteristic of lagged interdependence instead of simultaneous one, the model adjusts gradually and thus, Pollak argues that it is more tractable.

demand function that represents the necessary quantity of the good. Dealing with the way of developing the model, Pollak starts from the short-run per capita demand functions and their interaction, afterwards, by using theory he established the conditions under which a long-run equilibrium exists.

Granovetter and Soong (1986) presented another way in which interdependent preferences can be addressed mathematically. Focusing explicitly on Bandwagons and Snobs, and by means of demand schemes based on probabilities, Granovetter and Soong developed a dynamic model that also assumes lagged interdependent preferences. Although, these authors represented the lagged interdependent preferences using a probability density function to distribute thresholds that determined if the individual buys or stop buying the good. The thresholds defined the minimum and maximum levels of lagged consumption by the other consumers under which each individual was going to make his/her purchasing decision. By including a simplified supply side of the market and consequently evaluating the supply-demand interaction, the existence of stable price-quality equilibria is corroborated, clarifying that the model is asymptotically unstable for various possible parameter values (Granovetter & Soong, 1986).

As it was explained, the existence of endogenous preferences generated by the human desire to mimic the consumption patterns of reference groups, and the further conceptualization of this as Bandwagon and Snow effects, have been present in economic literature already for more than a century. Still, the way of including this effects, so evident by now, in consumer theory is rather quite limited. Thus, given the limitation of explicability and relevance that these kinds of endogeneities give to the current consumer theory, there are more than enough reasons to justify further attempts to mathematize Bandwagon and Snob effects. Exactly this is what I do in the model that will be presented in Section 3.

To set up the model I use the demands derivation scheme presented by Pollak (1976). However, I simplify the economy to two goods, and include the concepts of Bandwagon and Snob effects as the interdependent preferences in the model with non-linear dynamics. Therefore, two different forms of interdependent preferences are included, and consequently, there are two adjustment equations with different coefficients representing the interdependence. Furthermore, I represent the interdependence of preferences as changes in the

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weights of the utility function instead of changes in the necessary consumption. Additionally, I give a different interpretation of the parameter used for necessary consumption. Finally, I take the idea of using benchmarks as Granovetter and Soong (1986). Even though, I abstract from the use of any kind of distribution functions.

3 Model of Bandwagon and Snob effects

For the purpose of this thesis, and to keep the equations as simple and clear as possible, I assume an economy with two representative consumers and two goods.

Consumers are represented in the equations by the superindexes, r for the one with high income, and p for the one with low income, or $i \in \{r, p\}$. For the goods, z will represent the status good that was introduced to the market in the first period[10], and X for simplicity will represent the market basket of other goods and services. I assume consumers derive utility just from these two kinds of goods. Furthermore, the weights in the utility functions for these two kinds of goods are represented by α.

In respect to the functional form of the utility, a case of the *"Bergson Family"* of utility functions presented by Pollak (1971) was used[11]:

$$U_t^i(X, z) = \alpha_t^i \log(X - b + 1) + (1 - \alpha_t^i) \log(z + 1) \qquad (3.1)$$

Where

$$\alpha_t^i \in [0, 1]$$

$$(X - b + 1) > 0$$

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[10]Is important to clarify that the nature of the status good assumed here is not entirely conspicuos. This means that as a good designed for the high-income individual it has an intrinsic value itself, that is boosted by the distinction and status that it can generate. For example, subscribing to a satellite television provider can be seen as a sign of status for people in low-income countries but it doesn't mean that the only value of a subscription is given by the desire of displaying wealth.

[11]The only restriction on the utility function's concavity is $X - b > -1$. The derivation can be found in Appendix B. Given the assumptions provided in the following paragraphs for the terms in this restriction is logical to say that $X - b$ will always be positive for the High-income consumer. Therefore the restriction on concavity might be problematic just in the case of the low-income consumer, in this case $X - b$ will be equal or close to zero given the assumption of $w^p \approx b$ that will be explained afterwards. Thus, the concavity condition holds when the sacrificed consumption of the market basket is lower than one unit. Furthermore, in the Python simulation the plus one in both terms of the utility function is included as the variable a, thus, it can be modified to any value. Consequently, this restriction can be expressed as $X - (b - a) > 0$. under this set-up the $b - a$ can have an alternative interpretation as the subsistence level of consumption.

and b represents the usual level of consumption of the market basket of goods and services[12] by the low-income consumer, and therefore has to be positive. It is assumed that none of the consumers have a recommended consumption of the status good, thus, b or a homologous is not included in the second term of the utility function[13]. It is clear that regardless of the income level, things such as premium quality food or expensive subscriptions to satellite television providers are goods that people can omit in their consumption. Still, these goods give status and have an intrinsic utility.

From the utility function it can be noted that the sum of the weights is equal to one as a normalization. Furthermore, in the context of this model it is logical to assume that the values of alpha for the initial period should be $\alpha^p = 1$ and $\alpha^r \in [0, 1)$; representing with this that the low-income consumer's utility does not depend on the status good at the beginning, while for a high-income consumers it does. The reason for this is that the low-income consumer at the beginning need to observe the consumption by the high income to realize the status value that the good can provide. Afterwards, this consumer will start to adjust his/her income towards the status good and the optimal demands will change progressively. Under some specification of the parameters in the model, like the one presented in next section, there are some periods at the beginning in which even though the weights in the utility function get modified, the optimal amounts demanded remain the same. These periods can be interpreted as the time in which the low-income consumer decides how to modify his consumption to be able to purchase the status good. While the high-income consumer will purchase the good immediately.

As for the budget constraint necessary for the utility maximization process,

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[12]It is important to highlight that this usual level of consumption of the market basket does not represent the aggregation of goods and services necessary to survive, but by far more generous level of consumption. An example of this is the market basket that countries use to calculate the consumer price index, this basket attempts to represent the typical consumption of the average household of a determined income group. Therefore, it can be said that b represents the consumption of this kind of basket for a low-income individual.

[13]The use of a parameter representing a minimum level of consumption desired is used by Pollak (1976), the main difference is that he assumes that b is psychologically determined. Thus, the dynamics of Pollak's model are based on the variation over time of this parameter. He also uses the same setting for habit formation analysis.

there are two things that are important to mention. First, the income of both consumers will be assumed constant over time, something realistic in the sense that wages are usually fixed for long time periods, usually yearly. Second, the price of the market basket will be normalized to unity, as a way to simplify the equations and to represent the price of the status good as a proportion of the price of the market basket. Therefore, there will only be one price as a variable in the model, the one of the status good represented by P. Based on this, the budget constraint will be as follows:

$$X_t^i + Pz_t^i = w^i \tag{3.2}$$

Additionally, given the normalization for the price of the market basket, it is coherent to assume that $w^p \approx b$. Given this, the starting point of the model is when the low-income consumer is purchasing the usual basic basket that he/she was consuming before the introduction of the status good. Additionally, in most non-rich economies, the usual level of consumption is attempted to be guaranteed by establishing a minimum wage, and yet an important proportion of the inhabitants of these countries get at most that level of income[14]. This means that the low-income consumer has an income close or equal to the value of the recommended consumption of the market basket. Therefore, to consume z he/she will have to sacrifice part of his/her consumption of X. Consequently, the low-income individual will end up demanding less of the market basket than the socially recommended amount. The examples of satellite television and Subramanian and Deaton's empirical findings on the demand for calories presented in the introduction are consistent with this kind of behavior where the consumer deviates from more appropriate goods following his/her status desire.

The next step in the formulation of the model is the maximization of (3.1)

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[14]RedLat (2016), an international labor investigation institution, presented and compared the labor market situation for several Latin American countries based on national surveys. From this study we can see that in countries like Colombia and Peru about half of the population live under a minimum wage. As these countries are not the ones with the worst economic conditions in the world, interpreting the low-income's consumer wage as a minimum wage is not misleading. The coherence of w^p being approximately equal to b is also empirically supported by the article presented by the *BBC* in (2016). The information presented in this article implies that in almost half of the countries in the world, 100% or more of the minimum wage is needed to purchase the basic market basket.

with respect to (3.2). That will yield the following demand functions[15]:

$$z_t^{i*} = \frac{(1 - \alpha_t^i)}{P}(w^i - b + 1) - \alpha_t^i \tag{3.3}$$

$$X_t^{i*} = \alpha_t^i(w^i - b + 1 + P) + b - 1 \tag{3.4}$$

Both demand functions increase in the income of the individuals w; this means that if the individual has a higher purchasing power he/she will consume more of both goods. An increase in the consumption of both goods given an income shock is consistent with the CES shape of the indifference curves of the utility (Pollak, 1970). If the prices doesn't change, slope of the budget contraint will not change either, thus, an increase in w will produce a jump to a better indifference curve and the consumption of both goods will increase. Furthermore, in respect to the relation between demands and P, for z the demand decreases when P increases, and for X increases when P increases. It is coherent that if status good becomes more expensive the demand for it will fall, as it happens to the demand for z. While if we look to the crossed effect, if the price of the status good in the economy increases the demand for X should increase, representing a substitution effect given the change in the slope of the budget constraint.

With (3.3) and (3.4) the equilibrium demand for each kind of good by each consumer can be calculated period by period. In what concerns the dynamics of the model, the Bandwagon and Snob effects will be represented as the variation of the weights in the utility function for each of the two consumers. The weights in the utility function represent the importance that each consumer gives to each good, consequently, the adjustment over time of these weights represent the endogeneity of preferences. Both of the dynamics depend on lagged consumption of the status good. The dependence on past consumption attempt to represent the time that it takes consumers to be able to observe what others are consuming. That is to say, the time it takes for a good to get popular among consumers[16]. All of this shows the imperfect information in the market, as consumers can't know the real amount of a good consumed by others immediately, as Leibenstein assumed (Granovetter

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[15]The step by step maximization can be found in Appendix C.

[16]Interdependent preferences models based on lagged consumption can be found in literature i.e. Pollak (1970),Pollak (1976),Granovetter and Soong (1986) and Van Herpen, Pieters, and Zeelenberg (2009).

& Soong, 1986), far from it, they have to wait until the consumption becomes observable.

Given this, the dynamics for the low-income consumers were modeled in the following way:

$$\alpha_{t+1}^p = \alpha_t^p + \beta[\max(0, z_t^{r*} - z_t^{p*} - \theta^p)]^2 \qquad (3.5)$$

Where

$$\beta < 0$$

I assume the low-income consumer to care about the gap between the high-income individual's consumption of the status good and his/her own consumption of the same good. This set-up represents that the low-income consumer is always comparing his/her consumption with the one of the high-income consumer, consequently, the consumer based on this comparison will determine his/her adjustment of weights among the goods available in the economy. As by the definition of Bandwagon, consumers want to mimic the consumption habits of the group they want to belong to, the gap between consumptions and its magnitude is a way of representing how much status the good can give, and how much consuming it will differentiate the individual from his/her peers.

Additionally, the benchmark θ is subtracted from the gap of consumption of the status good[17]. The benchmark determines the minimum gap of consumption that will make the low-income consumer find the good interesting enough to modify his/her consumption patterns. The main reason for including a benchmark is that the low-income consumer have to be rational enough to know that he can't exactly mimic the high-income's consumption because of the income differential, and therefore, he is willing to shorten the gap just partially according to his income. Given this, the gap of consumption of the status good will always be positive.

In this case β represents the Bandwagon effect. As can be seen from (3.5), the Bandwagon coefficient is multiplied by an always positive quadratic function that takes values greater than zero when the gap of consumption is larger than a benchmark represented by θ^p. Given this, β must always be negative

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[17]The use of benchmarks is not new in the literature of endogenous preferences. Granovetter and Soong (1986) developed a probabilistic model based on benchmarks.

to guarantee that a big enough gap generates a change in the next period's weights of the utility function, and consequently, a possible change in the optimal quantities demanded by the low-income consumer. A larger β will mean a faster adjustment, thus, a bigger Bandwagon effect.

As a final remark on the Bandwagon dynamics, it is important to highlight that due to the quadratic form, the bigger the positive difference is between the consumption gap and the benchmark, the bigger the effect on the α^p for the next period. This behavior of the dynamics of α^p is consistent with the definition of Bandwagon, as the gap becomes smaller the perceived status that the good can give gets reduced. Consequently, the good is less attractive for the low-income individual the higher is his/her own consumption of the same good, as the perceived status that an extra amount purchased can provide gets reduced. This is reasonable because as z^p grows the good is more common and thus, the status-driven changes in the demand should become smaller. Furthermore, this functional form is also consistent with the fact that the low-income individual can't sacrifice a big proportion of the market basket consumption.

In respect to the Snob effect, the dynamics are given as follows:

$$\alpha_{t+2}^r = \alpha_{t+1}^r + \delta\sqrt{\max(0, z_{t+1}^{p*} - z_t^{p*} - \theta^r)} \tag{3.6}$$

Where

$$\delta > 0$$

The high-income consumer is assumed to care about the increase in the amount of the status good consumed by the low-income individual period by period. The high-income individual should not care about an increase or decrease in the gap because since the beginning he/she is consuming the optimal amount of the status good that differentiates himself/herself from the low-income individual. That is to say, in the initial period the high-income consumer sets his/her optimal amount demanded, and with it determines the initial gap level. Then, a big enough reduction[18] of the status level, represented by the gap, will progressively reduce the status-driven consumption of the high-income individual. Consequently, the increase in the consumption of the status good by the low-income individual is a way of representing

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[18]This will depend on the benchmark level θ^r.

how the good loses its status properties period by period while it becomes common in every classes' consumption.

Additionally, the benchmark θ is subtracted from the increase in the consumption of the status good by the low-income individual. In this case the benchmark represents the minimum increase that the high-income individual will perceive as enough to reduce his/her status-driven consumption by modifying the weights in the utility function. Consequently, by limiting the adjustment of high-income consumer's consumption this benchmark is consistent with the assumption of a status good not entirely conspicuous. It is reasonable to have a benchmark because too small changes in consumption can be hard to observe, or alternatively, the high-income consumer is not willing to modify his/her consumption under too small reductions in the status provided by the good represented by the increase in z^p.

In this case δ represents the Snob effect. This coefficient is multiplied by a square root function that takes values greater than zero when the lagged increase of consumption by the low-income consumers is larger than a benchmark represented by θ^r. Given this, δ must always be positive in order to guarantee that when the increase in the observable consumption of the low-income individual is large enough, a change in the weights of the next period's utility function will be produced. A larger δ will mean a faster adjustment, thus, a bigger Snob effect.

The functional form of the Snob effect as a square root reduces importance to big jumps in the consumption of the low-income individual, but still guarantees an always increasing effect. This behavior of the dynamics of α^r is consistent with the assumption of a status good with a partial conspicuos nature. But also with the definition of Snob effect, high-income consumers perceive the good as losing its status nature when the ones from which he/she was trying to differentiate increase significantly their consumption of the good. Furthermore, this functional form is also consistent with the idea of a good with intrinsic utility, making possible that the level of consumption never reach a zero level due to the Snob effect.

Moreover, the two dynamics together make possible a smooth transition between periods as it will be shown with the Python simulation.

4 Python simulation

The Python file created allows the modification of all the parameters explained above. Therefore, the program allows to relax the assumptions that were mentioned in the specification of the model. The coding can be found in Appendix D. An interactive setting is also provided and explained for anybody to experiment and try different assumptions that could result reasonable for them. In case of wanting to run the model in a faster way, or just wanting to change one of the parameters at the time, a vector of values is provided.

The coding replicates the exact process presented above and in the Appendix C, with the possibility of running any number of periods given the right parameter values. For the purpose of this thesis I will present the results of a simulation for 24 periods. In this case the periods could appear to be months, making the assumption of the lagged interdependent consumption more intuitive. People will observe the state of the nature and then plan how to divide the upcoming monthly wage accordingly. Additionally, short periods of time as the 2 years used here, are consistent with the assumption of fixed wages and also provide a logical time frame for the analysis of endogenous preferences.

For the other initial values for the parameters necessary in order to run the simulation, the first one that is given by what was mentioned before is $\alpha^p = 1$. Furthermore, I will assume the wage of the low-income consumer, w^p, to be equal to 1 and for the high-income $w^r = 3$. Thus, as it was mentioned before, b should be equal to 1 as well[19]. The price of the status good will be assumed to be 0.2, being this $\frac{1}{5}$ of the income of the low-income class[20].

In order to define an initial value for α^r I use the findings of Subramanian and Deaton (1996) to make an interpretation of what should happen under

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[19]For simplicity I assume in the simulation w^p exactly equal to b.

[20]Assuming w^p as a minimum wage, and going back to the example of a status good as a subscription to a satellite television provider, a price of $\frac{1}{5}$ of this wage goes in accordance with the prices that can be found in the Colombian market for satellite television providers. For example, in Colombia the monthly subscription to Claro (2017) or DirecTv (2017) accounts for close to 20% of two fortnight minimum wages as can be checked in BanRep (2017).

an income shock. In this paper it is shown that only 35% of the extra income is used in necessities consumption represented by calories for the poor. Therefore, for wealthier consumers it is reasonable to think that the proportion will be lower. Given that $w^p = 1$ and $w^r = 3$, the low-income consumer needs a shock of two units of income to have the same wage as the high-income consumer. Consequently, following the findings of Subramanian and Deaton an income shock of two units should represent an increase in the consumption of necessities of about 0.7. That is to say, under the setup of this simulation an individual with a wage of 3 should consume maximum 1.7 units[21] of the market basket. An $\alpha^r = 0.5$ is an accurate and simple initial value that allows to show what was stated before in this paragraph. As we can see from the following equations with an initial $\alpha^r = 0.5$ the demand for X^r in the first period will be lower but close to 1.7:

$$X^r = \alpha^r (w^r - b + 1 + P) + b - 1$$
$$X^r = 0.5(3 - 1 + 1 + 0.2) + 1 - 1 = 1.6$$

With a price for the market basket equal to 1, the total expenditure in this basket for the high-income individual will be also 1.6. This goes in accordance with what was mentioned before.

For the other parameters the initial values are less empirically supported, given the fact that they represent the quantification of psychological and behavioral aspects that haven't been widely studied. For the Bandwagon and Snob effects, it is important to highlight that the coefficients will represent the proportion of the squared gap of consumption, or the squared root of the increase of consumption by the low-income of the status good, that will become a change in the weights of the utility function for the next period. Given the bigger wage and the restriction represented by $w^p = b$ the change in α^p has to be bigger than the one in α^r to generate a representative change

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[21]This number comes from the initial consumption of the market basket by the poor, that will be equal to 1 given the parameter values already provided, plus the 0.7 units of necessities that the low-income consumer could be expected to spend on this given the findings of Subramanian and Deaton (1996). Theoretically the elasticity income of the demand of necessities should be maximum for low-income consumers. Therefore, for the high-income consumer is logical to think that in his way to have a high income he ended up with a maximum consumption of the market basket of 1.7. Thus, the initial level of consumption presented in the simulation will be coherent with this maximum.

in the demand per period, this is fixed by the functional form of the dynamics. Together with the condition that $\alpha_t^i \in [0,1]$ the Bandwagon and Snob effects' coefficients have to be a number in the hundredths to make the interpretation of the periods in the simulation as months coherent[22]. Given this, for the purpose of the simulation, a $\beta = -0.01$ and $\delta = 0.03$ will be used. As an important remark, this doesn't mean that the Snob effect is stronger than the Bandwagon in any form, this due to the difference in magnitudes of the elements that represent each effect in the dynamics equations. Thus, the coefficients can be seen as the speed of adjustment subject to the magnitude of the gap used in each dynamic equation.

The last parameters to be determined are the benchmarks used in the dynamics. Again, from the existent literature on interdependent preferences there is no way of stating an accurate empirically-based assumption on what should be the optimal level of benchmark that consumers should care about. Therefore, what I try to represent with the two values for the benchmarks is that they are coherent with the rest of assumptions already made. Consequently, the values of the θs were determined conditionally on the initial value of gap in each adjustment function. Based on that, to determine a value for θ^p first we need to calculate the value of $z^{p*} - z^{r*}$ in the first period. To do this I will evaluate (3.3) with all the values already provided for the first period. As we can see from the following equations the initial magnitude of this gap is equal to 7:

$$z_t^{i*} = \frac{(1 - \alpha_t^i)}{P}(w^i - b + 1) - \alpha$$

$$z^{p*} = \frac{(1 - 1)}{0.2}(1 - 1 + 1) - 1 = 0$$

$$z^{r*} = \frac{(1 - 0.5)}{0.2}(3 - 1 + 1) - 0.5 = 7$$

The value taken for θ^p will be equal to 4.5, this means that only when the gap of the consumption of the status good between the two kinds of consumers is

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[22]Bigger coefficients will generate faster adjustments and smaller coefficients slower adjustment. Depending on the characteristic of the good subject to endogenous preferences and the desired interpretation of the time periods the magnitude of the coefficients can be changed. For the purpose of this simulation and the interpretation of periods as months, placing them in the hundredths is the most useful option.

higher than 4.5 units of the good the Bandwagon effect will be active. This implies that low-income consumers are willing to shorten the gap in about 35% of the initial level. If we analyzed this from the perspective of a myopic consumer, this would mean that the low-income consumer is willing to buy up to 2.5 units of the status good. Purchasing this amount will represent spending half of his minimum wage in the status good. Even though it seems extreme, we have to remember that the market basket has nothing to do with the subsistence level of consumption, that can be as low as 21 dollar cents per day for some countries at P.P.P. as Subramanian and Deaton (1996) stated. Therefore, even if the case of sacrificing half of the minimum wage will never happen because the Snob effect is also active, it is not counter-intuitive that consumers could reduce their market basket consumption to half.

Lastly, the value for θ^r will be determined also conditional on the gap used in the adjustment equation for the high-income individual. In this case I will base the assumed value of the benchmark in the magnitude of the first increase of z^p. From the results tables in Appendix D we can see that this first jump in the consumption of the status good by the low-income consumer happens in the fifth period and is equal to 0.125 units. Consequently for the simulation, the benchmark in the high-income's adjustment function has to be lower than this value, thus, a $\theta^r = 0.01$ will be used. Even though the value might seem too small, it is consistent with its purpose of being limiting just when the increase in z^p is too small to be observable.

One may think that with a constant growth of status good consumption under the benchmark would mean that the low-income consumer will catch up with the high-income without activating the snob effect. But we have to remember that the increase of z^p takes its maximum value in the first periods after the bandwagon effect modify the optimal demands. Therefore, the benchmark only represents a restriction to the Snob effect in late periods. The main purpose of this is to represent the impossibility of observing really small changes, in certain way this can be explained by habit formation, as the one presented by Pollak (1970). The high-income consumer already sees as normal a positive consumption of the status good by the low-income individual. Consequently, in the late periods, when the changes in z^p are minimal, the high-income consumer is not willing to modify more his/her consumption. This again, because the value of the good is not only determined by the status that it provides.
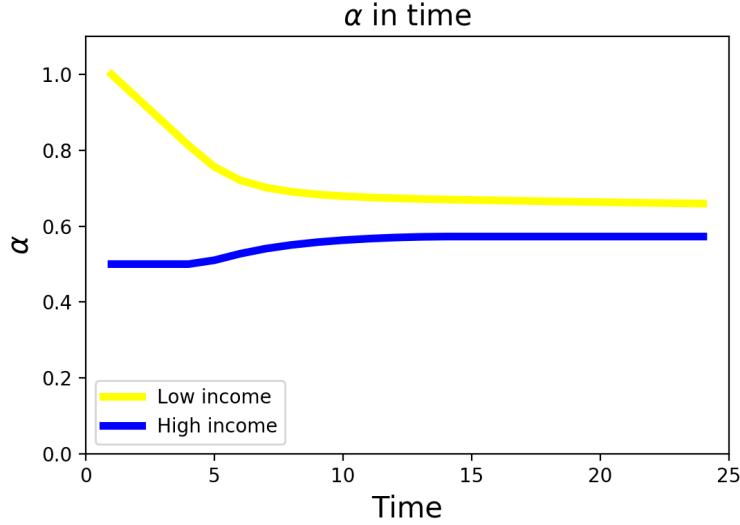
Figure 1: Variation over time of α from the Python simulation.

The tables of results for the simulation under these parameters for 24 periods can be found in Appendix D, the graphical results are presented in figures 1, 2 and 3. From Figure 1 we can see the behavior over time of the alphas for the two kinds of consumers. The graphs suggest a convergence of α^p to approximately 0.61, while for α^r to approximately 0.57. As it can be noticed, the change in α^p is several times bigger than the one in α^r, this goes in accordance with what was stated in the establishment of the model. Given the restrictions, a bigger change in the alpha of the low-income consumer is needed to generate a change in his/her consumption behavior.

In respect to the consumption of the goods, and starting with the status good, Figure 2 also suggests convergence. The consumption of the status good as expected, decrease for the high-income individual and increases for the low-income one. The final value for z^r converges approximately to 5.8, while z^p to approximately 1.3. The magnitude in which the consumption of the status good decreases might seem small, but it is consistent with the assumption of a not entirely conspicuous good. Furthermore, the final change in consumption in terms of units, given the Bandwagon and Snob effects is
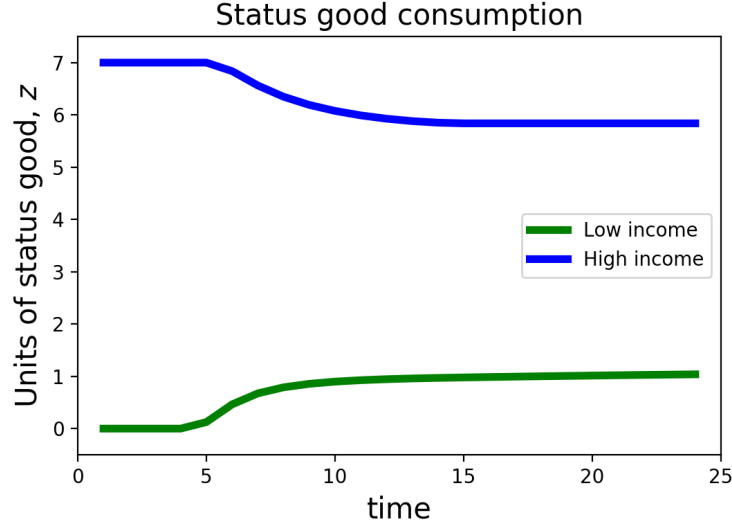
22

Figure 2: Variation over time of the consumption of the status good from the Python simulation.

not that different for this case, which is coherent with the comments made about the coefficients.

For the consumption of the market basket, the Figure 3 is provided, this graph also suggest a convergence, that is logical given the convergence of z and the assumption of an economy of two goods. X^r approximately tends in this case to 1.8, while X^p approximately tends to 0.7. As we can see from these results, the low-income consumer ends up sacrificing about 30% of his/her wage following his/her desire for status. This sacrificed amount goes in accordance with what was intended to be shown.

All the results found under the simulation are reasonable given the assumptions made, and show a way in which the Bandwagon and Snob effects might work. The high-income consumer never stops buying a good that was designed for him/her, but reduces his/her consumption given the decrease in the status that the good presupposes. This due to the consumption of the same good by the low-income class. While for the low-income consumer, by following his/her desire to emulate the consumption of the class he/she wants to belong to, just a reasonable proportion of his/her wage is sacrificed to con-
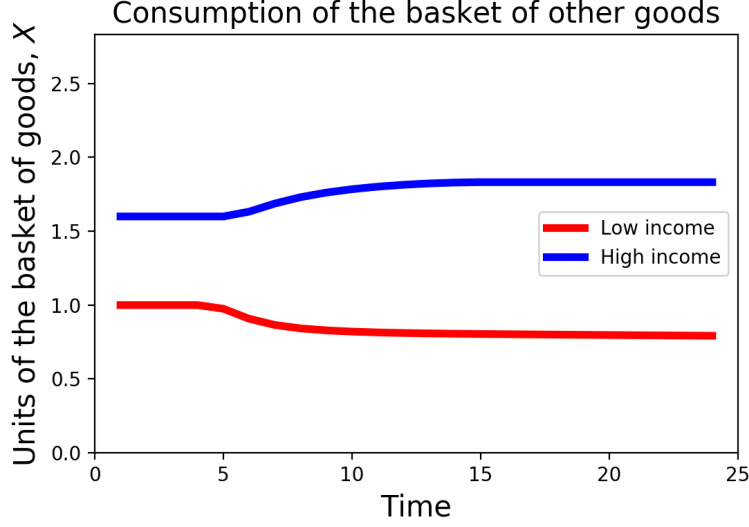
Figure 3: Variation over time of the consumption of the basket of other goods from the Python simulation.

sume the status good. Furthermore, the final gap in the consumption of z converges to a value of 4.5, as the θ^p established for the simulation suggested.

Additionally, it is interesting enough to analyze the results of the simulation for the first five time periods. As we can see, the αs get modified since the first period but the demand for the status good by the low-income consumer changes just until period five[23]. As it was mention before, this interval of periods in which the low-income consumer clearly know of the existence of the status good but doesn't consume it yet can be associated with the stage of budget planning. The low-income individual will progressively adjust the distribution of his/her income by cutting the spending on the market basket, this can be seen as the change in α^p but just until period 5 will be able to redistribute his/her income in a way that allow him/her to purchase the status good.

As a final remark on this Python simulation, even though the suggested

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[23]Therefore, as the high-income consumer's adjustment equation depends on changes of z^p, the weights of his/her utility function will get modified after the bandwagon effect generate quantitative changes in z. That is to say, z^r will start to change in period 6.

convergence to certain values after some time periods implies the existence of an equilibrium, there is a tractability problem when we try to solve the equilibrium by hand. Given the way in which the dynamics of the model work[24], the only way I have found by now to solve the equilibrium by hand requires the iteration of the new values for the alphas for each period, what presupposes an arduous and time-consuming task, but will end up with the same results found with the use of Python.

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[24]The adjustment formulas were not made as a linear variations period by period, but as an exponential one that depends on variations of the past consumption. Therefore, each period the variation in the alphas is different.

5 Discussion

I presented and simulated a dynamic model of interdependent preferences for an economy of two representative consumers with different income levels and two goods, of which one provided status. I started from the demand functions derived from a member of the Bergson Family of utility functions, and non-linear adjustment formulas based on the Bandwagon and Snob effects that modify the weights in the utility function period by period. Additionally, the adjustment was based on different gaps of the lagged consumption of the status good by both consumers, and benchmarks defining the minimum value under which the effect was going to be active.

Given the parameter values used in the simulation, after 15 periods the values to which the demands and α converge can be determined. The consumption of the status good increases for the low-income consumer and decreases for the high-income consumer. The magnitude of the variation of the demands is similar across consumers, although α^p changed more than α^r. This because the low-income consumer needs bigger changes in the weights of the utility function to modify his/her consumption given that his/her income was tied to the price of the market basket as an assumption.

Based on the results of the Python simulation it is not misleading to think that is feasible to get to an equilibrium. The equilibrium is represented by the steady final values of the demand functions after being adjusted for several periods due to the Bandwagon and Snob effects. This equilibrium can accurately represent observable examples of preferences endogeneity, where low-income consumers must sacrifice part of their normal consumption following their desire to attain status.

Finally, the model and simulation presented here give an example of one way in which the status-driven consumption can be mathematized and included in consumer theory. Consequently, this might be useful to anybody who is interested in a more complete approach of how to represent consumers' behavior. Furthermore, the Python code that is provided is a useful tool that can be easily modified under any specification.

5.1 Limitations

The simplification of the economy to two goods represents a problem when analyzing the behavior of the high-income consumer. Under this set-up, the Snob effect makes the high-income consumer substitute the status good for more consumption of the market basket. Although the reduction in his/her demand is intuitive, the shift should be towards a similar good.

Another limitation comes from the need of determinants of the benchmarks and empirically supported values for coefficients of the Bandwagon and Snob effects. The value for these variables was determined based on the coherence with the rest of the simulation, but there isn't a way of determining an optimal value based on empirical researches.

Finally, the arduous and time consuming work that is required to get to the steady demands by hand represents also a limitation of this thesis.

5.2 Model extensions

In accordance with the first limitation of the model mentioned, an interesting enough extension is to include other status goods, giving the option for the high-income individual to substitute his/her consumption not with the market basket but with another good that provides status. Under this case the analysis for the low-income consumer's behavior should focus more on the maximum amount of the recommended consumption of the market basket that can be sacrificed. That is to say, the subsistence level of consumption should matter, and the sacrificeable part of the income will be divided to consume the goods that could provide more status.

Additionally, another extension of the model could consider the effects on consumer welfare of the sacrifice of the market basket for the low-income individual. As presented by Subramanian and Deaton (1996), not consuming the right amount of calories have negative effects on productivity. For this extension of the model the effect of not consuming the usual amounts of goods and services could be represented as a reduction of the future wage. The reduction can be based on the consumption gap between X^p and b.

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A   Satellite T.V. and poverty

The two following pictures from Venezuela were retrieved from (*Ranchos con Directv, ya no es un lujo (Poor households with satellite television, it is not a luxury anymore; translated from spanish)*, 2009).

The following picture from Paraguay was retrieved from (EFE, 2014).

B Concavity of the utility function

To guarantee concavity in each kind of good the first derivative w.t.r to each good have to be positive and the second derivative negative:

$$\frac{\partial U(X,z)}{\partial z} \geq 0 \qquad\qquad \frac{\partial U(X,z)}{\partial x} \geq 0$$

$$\frac{(1-\alpha)}{z+1} \geq 0 \qquad\qquad \frac{\alpha}{X-b+1} \geq 0$$

While assuming non-negative consumption for both of the goods is enough to guarantee that the first derivative of (3.1) w.r.t z will be positive, for the case of the derivative w.r.t X a further condition is needed; $X - b > -1$

$$\frac{\partial^2 U(X,z)}{\partial^2 z} \leq 0 \qquad\qquad \frac{\partial^2 U(X,z)}{\partial^2 x} \leq 0$$

$$\frac{-(1-\alpha)}{(z+1)^2} \leq 0 \qquad\qquad \frac{-\alpha}{(X-b+1)^2} \leq 0$$

The negativity of the second derivative given non-negative consumption is always achieved. Furthermore the bivariate function is concave if the second derivatives are negative, condition that was already proved, and if also the cross derivative is positive:

$$\frac{\partial^2 U(X,z)}{\partial z \partial x} \geq 0$$

$$0 \geq 0$$

Therefore, the utility function is concave. The concavity of the function means diminishing utility in both of the goods, this means that the more the individual have of one good the more is willing to exchange for an unit of the other. In this way the consumer wants a mixed basked. Furthermore, it is useful for a dynamic analysis and the derivation of demand functions.

C   Derivation of demand functions

The demand functions for both X and z come from the maximization of (3.1) w.r.t. (3.2). In order to do this we can solve for X in (3.2) and plug the result in (3.1) to get:

$$U^i(X(z, w^i), z)$$

Now that the constraint is already included in the function we can simply take the derivative of $U^i(X(z, w^i), z)$ w.r.t z:

$$\frac{\partial U^i(X(z, w^i), z)}{\partial z} = 0$$

$$\frac{P\alpha^i}{w^i - Pz - b + 1} = \frac{(1 - \alpha^i)}{z + 1}$$

$$\alpha^i Pz + \alpha^i P = w^i - Pz - b + 1 - \alpha^i w^i + \alpha^i Pz + \alpha^i b - \alpha^i$$

$$Pz = (1 - \alpha^i)w^i + 1 - \alpha^i - b(1 - \alpha^i) - \alpha^i P$$

$$z^{i*} = \frac{(1 - \alpha^i)}{p}(w^i - b + 1) - \alpha^i$$

Now the z^* can be plugged in (3.2) to get X^*:

$$X = w^i - Pz^{i*}$$

$$X = w^i - (1 - \alpha^i)(w^i - b + 1) + \alpha^i P$$

$$X^{i*} = \alpha^i(w^i - b + 1 + P) + b - 1$$

The same maximization occur every period and therefore the demands can be indexed with t.

D   Bandwagon and Snob effects. Python simulation.

The program can be downloaded as an iPython/Anaconda notebook from the following link: https://1fichier.com/?hc3m63wo1v. Or as a normal Python file from: https://1fichier.com/?b650w7j8pq. In this section I present the codes and results of the simulation.

```python
import math                          # In the first five lines of code I import all the relevant
from scipy import optimize          # libraries to run the simulation.
import matplotlib.pyplot as plt
from matplotlib.ticker import NullFormatter
%matplotlib inline

def budconst(z,p,w): # This equation is equal to (3.2) solving for X.
    return w-z*p

def utility(x,z,a,b,alpha): # This equation is equal to (3.1).
    u= alpha*(math.log10(x-b+a)/math.log10(math.e))+(1-alpha)*(math.log10(z+a)/math.log10(math.e))
    return(u)

def alpha_poor(alpha,beta,theta,z_r,z_p): # This equation is equal to (3.5).
    alpha= alpha+beta*(min(0,(theta-z_r+z_p))**2)

    return(alpha)
def alpha_rich(z_lag,alpha,beta,theta,z_r,z_p): # This is equation is equak to (3.6).
    return(alpha+beta*(math.pow(max(0,z_p-z_lag-theta),(1/2))))

result=[['t','u_p','x_p','z_p','alpha_p','u_r','x_r','z_r','alpha_r']]
tl=[]          # The coding lines starting from "result" until "alpha_rl" are used to generate the lists of
u_pl=[]        # results used for the tables and graphs in the command cells of this notebook.
x_pl=[]        # "t" refers to the list of periods.
z_pl=[]        # "u_i", "x_i", "z_i" and "alpha_i" refer to the utility, consumption of the market basket,
alpha_pl=[] # consumption of the status good, and alpha respectively.
u_rl=[]        # "i" is equal to "p" for the low-income individual and "r" for the high-income individual.
x_rl=[]
z_rl=[]
alpha_rl=[]

def main(result,tl,u_pl,x_pl,z_pl,alpha_pl,u_rl,x_rl,z_rl,alpha_rl): # A main is established as the beggining of the
    print('To run the simulation presented in the thesis type "1".') # simulation program. Thus, the main depends on
    print('If you want to change the values of the variables type "2".') # all the variables mentioned avobe.
    menu=input().strip() # This line of coding altogether with the two above generate the initial interactive menu.
    if menu=='1': # When the option "1" is choosen the simulation used for the analysis in the thesis will be run.
        VectorOfValues_g=[[24,'t'],[1,'a'],[1,'b'],[0.2,'p']] # The three "VectorOfValues" include the values for all
        VectorOfValues_p=[[1,'a_p'],[-0.01,'b_p'],[4.5,'t_p'],[1,'w_p']] # the variables used in the thesis.
        VectorOfValues_r=[[0.5,'a_r'],[0.03,'b_r'],[0.01,'t_r'],[3,'w_r']] # The "VectorOfValues" that ends with a "p"
        t=VectorOfValues_g[0][0] # presents the low-income individual specific variable values. The same goes for the
        a=VectorOfValues_g[1][0] # one that ends with a "r" but for the high-income consumer. Finally, the one that
        b=VectorOfValues_g[2][0] # ends with a "g" presents general variable values as time and price of "z".
        p=VectorOfValues_g[3][0]
        alpha_p=VectorOfValues_p[0][0]
        beta_p=VectorOfValues_p[1][0]
        theta_p=VectorOfValues_p[2][0]
        w_p=VectorOfValues_p[3][0]
        z_p = 0 # Given the assumptions of the model, the innitial consumption of the status good for the low-income
        x_p = max(0,budconst(z_p,p,w_p)) # consumer can be already determined as equal to zero. Therefore, the market
        alpha_r=VectorOfValues_r[0][0] # basket consumption for this individual will be equal to the result of
        beta_r=VectorOfValues_r[1][0] # plugging "z=0" in budconst. The maximum function is used to assure
        theta_r=VectorOfValues_r[2][0] # non-negative consumptions.
        w_r=VectorOfValues_r[3][0]
```

```python
        w_r=VectorOfValues_r[3][0]
        z = optimize.minimize_scalar(lambda x: -utility(budconst(x,p,w_r),x,a,b,alpha_r),bounds=(-1,w_r/p),method='bounded')
        z_r = max(z.x,0) # The line of code above uses a minimizer to calculate the consumption of "z" for the high-income
        x_r = max(0,budconst(z_r,p,w_r)) # consumer. Given this, the function minimized is equal to "-utility". To avoid
        # using a Lagrangian, "x" in terms of "z"(budconst) is plugged in the utility function. The use of x as the
        # minimizing variable is due to a requirement of the minimizing routine. The rest of the codes that use the
        # minimizing routine in this program follow the same logic. The routine is used indistinctively for high and low
        # income consumers. Furthermore, non-negativity condition is assured by the coding line after each minimization
        # with the use of a maximum function. Finally, the consumption of "x" is always calculated by plugging in the
        # optimal demand for "z" into the budget contraint (budconst).
elif menu=='2': # In case of wanting to change the initial values of the variables the option "2" in the menu is
        t=int(input("Number of periods:")) # provided. The program will ask you to type all the new values.
        a=float(input('Value for "a":'))
        b=float(input('Value for "b":'))
        p=float(input("Price of the status good:"))
        alpha_p=float(input('Value for low-income`s "alpha":'))
        beta_p=float(input('Value for low-income`s "beta":'))
        theta_p=float(input('Value for low-income`s "theta":'))
        w_p=float(input('Income of the low-income individual:'))
        z_p = 0
        x_p = max(0,budconst(z_p,p,w_p))
        alpha_r=float(input('Value for high-income`s "alpha":'))
        beta_r=float(input('Value for high-income`s "delta":'))
        theta_r=float(input('Value for high-income`s "theta":'))
        w_r=float(input("Income of the high-income individual:"))
        z = optimize.minimize_scalar(lambda x: -utility(budconst(x,p,w_r),x,a,b,alpha_r),bounds=(-1,w_r/p),method='bounded')
        z_r = max(z.x,0)
        x_r = max(0,budconst(z_r,p,w_r))
else:
        print('The input typed is not defined, please write a valid number ("1" or "2").')
        main(result,t1,u_p1,x_p1,z_p1,alpha_p1,u_r1,x_r1,z_r1,alpha_r1)

for i in range (t): # Given the dynamic nature of the problem, and in order to simplify the code as much as possible,
    try:            # I use a "for loop". Thus, the same maximization process is repeated period by period.
        if alpha_p<0:
            alpha_p=0          # The first two pairs of "if" and "elif" functions are defined to assure that the alphas
        elif alpha_p>1:        # always stay inside the interval [0,1].
            alpha_p=1
        if alpha_r<0:
            alpha_r=0
        elif alpha_r>1:
            alpha_r=1

        u_p=utility(x_p,z_p,a,b,alpha_p)
        u_r=utility(x_r,z_r,a,b,alpha_r)
        result.append([i+1,u_p,x_p,z_p,alpha_p,u_r,x_r,z_r,alpha_r]) # "append" function is used to generate the
                                                                      # lists of results.

        alpha_p=alpha_poor(alpha_p,beta_p,theta_p,z_r,z_p)
        if i==0: # Given the two periods lag of the dynamic of the high-income individual, an exception in the way
            alpha_r=alpha_rich(z_p,alpha_r,beta_r,theta_r,z_r,z_p) # of calculating alpha has to be made for the
                                                                    # first period.
        else:
            alpha_r=alpha_rich(result[i][3],alpha_r,beta_r,theta_r,z_r,z_p)
```

```python
        if alpha_p==0:      # When "alpha_p" is equal to "0" or "1" there's no need of using the minimizer.
            alpha_p=0
            x_p=0
            z_p=w_p/p
        elif alpha_p==1:
            alpha_p=1
            x_p=w_p
            z_p=0
        else:
            z = optimize.minimize_scalar(lambda x: -utility(budconst(x,p,w_p),x,a,b,alpha_p),bounds=(-1,w_p/p),method='bounded')
            z_p = max(0,z.x)
            x_p = budconst(z_p,p,w_p)
        if alpha_r==0:      # When "alpha_r" is equal to "0" or "1" there's no need of using the minimizer.
            alpha_r=0
            x_r=0
            z_r=w_r/p
        elif alpha_r==1:
            alpha_r=1
            x_r=w_r
            z_r=0
        else:
            z = optimize.minimize_scalar(lambda x: -utility(budconst(x,p,w_r),x,a,b,alpha_r),bounds=(-1,w_r/p), method='bounded')
            z_r = max(0,z.x)
            x_r = budconst(z_r,p,w_r)

    except: # Since the program allows the user to input any values for the parameters, this "except" tell how many periods
            # the model is able to run before generating a mathematical indetermination if it is the case, given the parameter
            # values provided by the user.

        print("This model can run up to",i,'periods')
        break


print("")                               # This code prints the lists of results.
for i in range(len(result)):
    print(result[i][0],result[i][1])
    if i>0:
        tl.append(result[i][0])
        u_pl.append(result[i][1])
        x_pl.append(result[i][2])
        z_pl.append(result[i][3])
        alpha_pl.append(result[i][4])
        u_rl.append(result[i][5])
        x_rl.append(result[i][6])
        z_rl.append(result[i][7])
        alpha_rl.append(result[i][8])

plt.figure(1)  # ALL the following codes generate the graphs. The next command cells replicate these
               # codes to generate better looking graphs.
#graph t,u_p
plt.subplot(221)
plt.plot(tl, u_pl,'-', color = 'b', linewidth = 2)
plt.title("t vs u_p",fontsize = 15)
plt.xlabel("Time",fontsize = 15)
plt.ylabel("Utility_p",fontsize = 15,rotation = 90)
plt.xlim(0,len(tl))
```

```python
plt.ylim(-0.1,max(u_rl)+0.1)

print("")
for i in range(len(result)):
    print(result[i][0],result[i][2])
#graph t,x_p
plt.subplot(222)
plt.plot(tl, x_pl,'-', color = 'b', linewidth = 2, label="Low income consumer")
plt.title("t vs x_p",fontsize = 15)
plt.xlabel("Time",fontsize = 15)
plt.ylabel("x_p",fontsize = 15,rotation = 90)
plt.xlim(0,len(tl)+1)
plt.ylim(0,max(x_pl)+1)


print("")
for i in range(len(result)):
    print(result[i][0],result[i][3])
#graph t,z_p
plt.subplot(223)
plt.plot(tl, z_pl,'-', color = 'b', linewidth = 2)
plt.title("t vs z_p",fontsize = 15)
plt.xlabel("Time",fontsize = 15)
plt.ylabel("z_p",fontsize = 15,rotation = 90)
plt.xlim(0,len(tl)+1)
plt.ylim(-0.5,max(z_pl)+1)

print("")
for i in range(len(result)):
    print(result[i][0],result[i][4])
#graph t,alpha_p
plt.subplot(224)
plt.plot(tl, alpha_pl,'-', color = 'b', linewidth = 2)
plt.title("t vs alpha_p",fontsize = 15)
plt.xlabel("Time",fontsize = 15)
plt.ylabel("alpha_p",fontsize = 15,rotation = 90)
plt.xlim(0,len(tl)+1)
plt.ylim(0,max(alpha_pl)+0.1)

print("")
for i in range(len(result)):
    print(result[i][0],result[i][5])
#graph t,u_r
plt.subplot(221)
plt.plot(tl, u_rl,'-', color = 'r', linewidth = 2)
plt.title("Time vs Utility",fontsize = 15)
plt.xlabel("Time",fontsize = 15)
plt.ylabel("Utility",fontsize = 15,rotation = 90)
plt.xlim(0,len(tl)+1)
plt.ylim(-0.1,max(u_rl)+0.1)
```

```python
print("")
for i in range(len(result)):
    print(result[i][0],result[i][6])
#graph t,x_r
plt.subplot(222)
plt.plot(tl, x_rl,'-', color = 'r', linewidth = 2,label="High income consumer")
plt.title("Time vs X",fontsize = 15)
plt.xlabel("Time",fontsize = 15)
plt.ylabel("X",fontsize = 15,rotation = 90)
plt.xlim(0,len(tl)+1)
plt.ylim(0,max(x_rl)+1)
plt.legend(bbox_to_anchor=(1.05, 1), loc=2, borderaxespad=0.)

print("")
for i in range(len(result)):
    print(result[i][0],result[i][7])
#graph t,z_r
plt.subplot(223)
plt.plot(tl, z_rl,'-', color = 'r', linewidth = 2)
plt.title("Time vs z",fontsize = 15)
plt.xlabel("Time",fontsize = 15)
plt.ylabel("z",fontsize = 15,rotation = 90)
plt.xlim(0,len(tl)+1)
plt.ylim(-0.5,max(z_rl)+1)

print("")
for i in range(len(result)):
    print(result[i][0],result[i][8])
#graph t,alpha_r
plt.subplot(224)
plt.plot(tl, alpha_rl,'-', color = 'r', linewidth = 2)
plt.title(r"t vs $\alpha$",fontsize = 15)
plt.xlabel("Time",fontsize = 15)
plt.ylabel("alpha",fontsize = 15,rotation = 90)
plt.xlim(0,len(tl)+1)
plt.ylim(0,max(alpha_pl)+0.1)

plt.gca().yaxis.set_minor_formatter(NullFormatter())
plt.subplots_adjust(top=0.92, bottom=0.08, left=0.10, right=0.95, hspace=0.8,wspace=0.8)


main(result,tl,u_pl,x_pl,z_pl,alpha_pl,u_rl,x_rl,z_rl,alpha_rl) # The main is closed here. Thus, the program ends.
```

```
To run the simulation presented in the thesis type "1".
If you want to change the values of the variables type "2".
1

t u_p
1 0.0
2 0.0
3 0.0
4 0.00151360019832
5 0.0193326060802
6 0.0393595646914
7 0.0529873513166
8 0.0617140939711
9 0.0674435848769
10 0.0713487404991
11 0.074116288563
12 0.0761613503354
13 0.0777469146508
14 0.0790513539353
15 0.0802217495088
16 0.0813492365631
17 0.0824360809422
18 0.0834843972641
19 0.0844961606227
20 0.0854732173267
21 0.0864172748129
22 0.087329971423
23 0.0882128229222
24 0.0890672510246

t x_p
1 1.0
2 1.0
3 1.0
4 0.974999928591
5 0.907312459709
6 0.865179557863
7 0.842059642469
8 0.828642404819
9 0.820288767483
10 0.814774279455
11 0.810946717193
12 0.808158809804
13 0.806019995992
14 0.804274799709
15 0.802719727225
16 0.801231105374
17 0.79980473531
18 0.798436766383
19 0.797123660634
20 0.795861491878
21 0.794648622463
22 0.793481582703
23 0.792357807637
24 0.791274921042
```

```
t z_p
1 0
2 0
3 0
4 0.125000357046
5 0.463437701456
6 0.674102210683
7 0.789701787653
8 0.856787975904
9 0.898556162584
10 0.926128602727
11 0.945266414034
12 0.95920595098
13 0.969900020041
14 0.978626001456
15 0.986401363876
16 0.993844473132
17 1.00097632345
18 1.00781616808
19 1.01438169683
20 1.02069254061
21 1.02675688768
22 1.03259208649
23 1.03821096182
24 1.04362539479
```

```
t alpha_p
1 1
2 0.9375
3 0.875
4 0.8125
5 0.75609376696
6 0.720983025296
7 0.701716614861
8 0.690535291354
9 0.683573886527
10 0.678978441822
11 0.675788776633
12 0.673465497356
13 0.671683134255
14 0.670228788885
15 0.668932881543
16 0.667692350246
17 0.666503695964
18 0.665363709818
19 0.664269443504
20 0.663218183268
21 0.662207448242
22 0.661234905071
23 0.660298416267
24 0.659396001628
```

```
t u_r
1 1.2747225854627857
2 1.2747225854627857
3 1.2747225854627857
4 1.2747225854627857
5 1.2585559664587844
6 1.2321767320430141
7 1.2123832385062057
8 1.1984794292544816
9 1.1885016100516959
10 1.1811939062634353
11 1.175834233081115
12 1.1720092559842845
13 1.1695160168681258
14 1.1684738223591116
15 1.1684738223591116
16 1.1684738223591116
17 1.1684738223591116
18 1.1684738223591116
19 1.1684738223591116
20 1.1684738223591116
21 1.1684738223591116
22 1.1684738223591116
23 1.1684738223591116
24 1.1684738223591116
```

```
t x_r
1 1.6
2 1.6
3 1.6
4 1.6
5 1.63255524943
6 1.68757256634
7 1.73057608749
8 1.76177233767
9 1.78470934862
10 1.80182003759
11 1.81454590232
12 1.82372272507
13 1.8297482353
14 1.83227737358
15 1.83227737358
16 1.83227737358
17 1.83227737358
18 1.83227737358
19 1.83227737358
20 1.83227737358
21 1.83227737358
22 1.83227737358
23 1.83227737358
24 1.83227737358
```

```
t z_r
1 7.0
2 7.0
3 7.0
4 7.0
5 6.83722375284
6 6.56213716829
7 6.34711956255
8 6.19113831163
9 6.07645325688
10 5.99089981207
11 5.9272704884
12 5.88138637463
13 5.85125882349
14 5.83861313212
15 5.83861313212
16 5.83861313212
17 5.83861313212
18 5.83861313212
19 5.83861313212
20 5.83861313212
21 5.83861313212
22 5.83861313212
23 5.83861313212
24 5.83861313212

t alpha_r
1 0.5
2 0.5
3 0.5
4 0.5
5 0.5101735107677279
6 0.5273663467749048
7 0.540805024474129l
8 0.5505538510329009
9 0.5577216658621632
10 0.563068755538937
11 0.5670455879630191
12 0.5699133449569055
13 0.5717963168769696
14 0.5725866725905959
15 0.5725866725905959
16 0.5725866725905959
17 0.5725866725905959
18 0.5725866725905959
19 0.5725866725905959
20 0.5725866725905959
21 0.5725866725905959
22 0.5725866725905959
23 0.5725866725905959
24 0.5725866725905959
```