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Preferences, Behavior and Needs

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4.01 The proposition is a picture of reality.

The proposition is a model of the reality as we think it.

Wittgenstein (1922)

Abstract

That demand patterns change with income something that can be inferred even in casual observation. Additionally, empirical research has underlined the nonlinearity of the relationship between income and demand described by Engel curves, with these nonlinearities appearing particularly robust for some expenditure categories. However, if demand-system estimation models have undergone significant development to be able to account for these patterns, theoretical explanations are still lagging.

This work fills the gap by providing modeling structures aimed at explaining the nonlinearity of the relationship between income and demand. In the two chapters, insights are drawn from psychology to embed preferences within an ordered-needs framework. The first of them introduces a general class of ordered non-homothetic preferences grounded on need satiation which allows for ordered and varying demand-income elasticities. The second proposes to combine ordered needs with path dependence by letting preferences adjust according to differential satiation. These models' ability to qualitatively reproduce nonlinear Engel curves suggest need satiation and ordered preferences might be important factors at play to explain this phenomenon.

Keywords: preferences; needs; income elasticity; Engel curve; demand theory.
JEL Classification: D01; D03; D11; D91.

Resumo

Que os padrões de consumo se alteram com o rendimento é algo manifesto. Ademais, a evidência empírica tem sublinhado a não-linearidade da relação entre rendimento e procura descrita pelas curvas de Engel, sendo estas não-linearidades particularmente robustas para algumas categorias de despesa. Contudo, se os modelos de estimação de sistemas de procura mostraram um forte desenvolvimento para serem capazes de detalhar estes padrões, a teoria tarda em explicá-los.

Este trabalho cobre esta lacuna ao apresentar estruturas visando a explicação das relação não-linear entre rendimento e procura. Nos dois capítulos, teses da psicologia são utilizados para incorporar as relações de preferências numa estrutura de necessidades ordenadas. O primeiro introduz uma classe geral de preferências não-homotéticas ordenadas baseada na satisfação de necessidades que permite elasticidades-rendimento da procura ordenadas e variando com o rendimento. O segundo propõe juntar necessidades ordenadas com dependência temporal ao permitir que as preferências se alterem mediante a saciedade marginal. A capacidade destes modelos em reproduzir qualitativamente curvas de Engel não-lineares sugere que satisfação de necessidades e preferências ordenadas podem ser factores relevantes para explicar este fenómeno.

Palavras-chave: preferências; necessidades; elasticidade rendimento; curva de Engel; teoria da escolha.

JEL Classification: D01; D03; D11; D91.

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I

Preface

Suppose a person gets a 20% raise. Common economic models predict that the person's expenditures on food would increase by 20% as well. Expenditures on, say, culture, furniture, or even alcohol, would also rise by 20%. However, when income actually increases by x%, it is likely *not* the case that all quantities increase by x%: some may increase proportionally more and others proportionally less. In general, when demand for a good increases proportionally it is said to have a unit income elasticity, while when it increases proportionally more (less) than income, income elasticity is positive but higher (lower) than one. Finally, when quantities decrease with income (negative income elasticity), the good are termed inferior. Yet theoretical models that cover all these possibilities are few and far between.

While there is some literature regarding inferior goods (Heijman and von Mouche, 2011), broad aggregates – such as foodstuff, clothing and housing – are unlikely to fall as income rises, as empirical evidence shows. This can be due to people who enjoy higher material comfort spending more in all categories, purchasing goods that address the same *needs* but are of higher quality. Nevertheless, there are still differences in income elasticities, shaping demand patterns not only across goods but also across categories of goods. For instance, the budget share – the fraction of income spent on a given good or category – allocated to food is persistently found to decrease while income rises, even if expenditure on food still increases.

This demand "stylized fact" of a below unity (but positive) income elasticity for food was famously asserted by Ernst Engel (1857) more than 150 years ago and has proved to be a robust empirical finding. However, despite the core role of demand in modern economic theory, the profession has not yet provided tractable functionals that account for this finding. Moreover, the standard repertoire of functionals used to describe preferences actually forces all income elasticities to be one, as it relies on homothetic and quasi-homothetic preferences. In other words, while the general theoretical framework allows for all sorts of income (and price) elasticities, economic models tend to rely on functions which impose that when income increases by x%, *all* quantities demanded increase by x% and thus, if prices are kept fixed, the individual spends exactly the same fraction of income on food, shoewear and traveling, whether the individual is just above the extreme poverty threshold or already enjoys an extremely high income.

Adopting homothetic functionals for tractability therefore has non-negligible impacts on model results. While alternative functionals do exist, these either put preferences in a black box, limiting the discussion of preference features and being descriptive rather than explanatory of behavior, or, instead, frustrate the application of standard analytical techniques relying on demand functions. Examples of the former are the data-fitting Translog (Jorgenson and Lau, 1975) and (QU)AIDS models (Deaton and Muellbauer, 1980a; Banks et al., 1997), while lexicographic and other algorithm-based preferences (Coursey, 1982, 1985; Drakopoulos, 1994) provide examples of alternatives that impose limitations unwarranted by the profession.

In this work, we discuss how an explicit ordering in preferences can account for different income elasticities of demand. The approach extends the standard framework of optimizing behavior by drawing attention to insights from psychology on how individuals rank different *needs* in a hierarchical fashion. We follow two distinct strategies. The first, in chapter II, is to define a class of preferences where a functional *structure* is imposed, in a static context. It is shown that a regular albeit non-homothetic function is capable of accounting for the kind of behavior found in empirical research. The second, in chapter III, is to associate the hierarchical nature of needs to demand-adjusting behavior within a dynamic setting. Each chapter constitutes an autonomous paper, therefore some overlapping will be present, especially when discussing the relation of this work with the existing literature. Details will be left to appendices, including digital appendices.

Both strategies are successful in relating the concept of income elasticity to the existence of an ordering of needs, where categories of goods associated to lower-order needs (e.g. survival needs) have the lowest income elasticity and income elasticity increases with the order of the need to which the good is related. The models here are better understood as models for different needs, not goods, as the same need might be satisfied by different goods. One can choose to buy more vegetables than meat, but one still needs food. A structuring of preferences according to needs might underlie the overall budgeting process.

Throughout, no assumptions are made on the specification of the list of needs – which is as tricky as defining other operationally crucial concepts commonly taken as given, such as the “relevant market” in industrial economics or the specification of the “reference” in behavioral models with gain-loss asymmetries. It would be possible for the hierarchy to be fixed or changing; for the needs themselves to remain the same; or for higher needs to be generated as expenditure grows. There are arguments in favor of any of these possibilities and the models presented are flexible enough to cope with all of them.

We show that enriching standard preference relations – transitive, reflexive, complete, smooth and convex – by positing an hierarchical structure of needs can account for different income elasticities. This is easily illustrated. Suppose that a middle-class person's budget falls drastically. Arguably, she will be more prone to cut down expenditure associated to higher-order needs, e.g. recreation, instead of sharply "economizing" on lower-order needs, such as food.

Different income elasticities for broad categories could be merely due to a composition effect, that is, the selection of different goods to satisfy the same need as income changes. However, the empirical regularity of, for instance, foodstuff budget shares being decreasing in income is valid for the broad aggregate as a whole. Hence, some overall structure of preferences over broad categories of goods might be assumed to exist. Moreover, our approach can also inform why some categories of goods which have high income elasticities at low income levels turn out to exhibit low income elasticities for a high enough income level. In other words, *why* income elasticities *change* with income might be associated to the ordering of needs, as higher-order needs may be activated when lower-order needs are sufficiently satisfied. If a given need is not satisfied at all and is then activated, additional income could be mostly directed towards satisfying this need. After a given need-satisfaction threshold (endogenous to the model and depending on prices and income), the next ordered need would be activated, leading to a decrease in the budget shares of lower-order needs. Income elasticity would thus be greatest for low levels of need satisfaction. This varying income elasticity is shown to happen in the two modeling strategies pursued.

> I think that it is a relatively good approximation to truth - which is much too complicated to allow anything but approximations - that (...) ideas originate in empirics, although the genealogy is sometimes long and obscure. But, once they are so conceived, the subject begins to live a peculiar life of its own and is better compared to a creative one, governed by almost entirely aesthetical motivations, than to anything else and, in particular, to an empirical science. There is, however, a further point which, I believe, needs stressing. As a (...) discipline travels far

> from its empirical source, or still more, if it is a second and third generation only indirectly inspired by ideas coming from "reality" it is beset with very grave dangers. It becomes more and more purely aestheticizing, more and more purely l'art pour l'art. This need not be bad (...) [b]ut there is a grave danger that the subject will develop along the line of least resistance (...). In other words, at a great distance from its empirical source, or after much "abstract" inbreeding, a (...) subject is in danger of degeneration. At the inception the style is usually classical; when it shows signs of becoming baroque, then the danger signal is up. (...).
>
> In any event, whenever this stage is reached, the only remedy seems to me to be the rejuvenating return to the source: the re-injection of more or less directly empirical ideas. I am convinced that this was a necessary condition to conserve the freshness and the vitality of the subject and that this will remain equally true in the future.
>
> (von Neumann, 1947, p. 196)

Though this (extensive) quote from John von Neumann addresses mathematics, it seems entirely applicable to the state of the art of demand theory. The urgency in refining the core of demand theory drawing from the known robust empirical evidence in order to account for observed regularities is critical for theoretical and empirical research alike and much work is still necessary. Although the general approach conceptualized here still has shortcomings – some inherited from the standard framework, such as the linearity of the budget constraint, others new, such as the need to assume a needs ordering in empirical applications –, it can also provide valuable insights. It also has the potential for additional features, such as nesting preference relations over goods within the same category.

We hope this contribution to the literature is fertile in generating more research in demand theory, revisiting classic topics with a refreshed perspective.

II

The Need for Needs

The Need for Needs. Ordered Preferences and Engel Curves

Abstract

Empirical evidence collected for over 150 years has highlighted the nonlinearity of the relationship between income and demand described by Engel curves. Nevertheless, theoretical models based on consumer constrained optimization struggle to bring about these findings and do not seem able to explain them. In this paper, insights are drawn from psychology to embed preferences within an ordered-needs framework. A general class of ordered non-homothetic preferences is proposed, enabling ordered demand-income elasticities that vary with income. The potential of this new class of preferences is illustrated and discussed with a simple example.

Keywords: preferences; hierarchical needs; income elasticity; Engel curves.

JEL classification: D01; D03; D11.

1. Introduction

> *Speaking very broadly, almost any human action involves choice; the external environment delimits a range of possible actions at any given moment but does not usually reduce that range to a single alternative. The formulation of a theory of human action in some sphere as a theory of choice means its presentation as a functional relation associating with each possible range of alternatives a chosen one among them.*
>
> (Arrow, 1958, p. 1)

The analysis of choice within the realm of economics has gone through great advancements in the last century and a half. The progressive focus on behavior, rather than pleasure or even decision making, associated to a sophisticated modeling framework have become a hallmark of economics. Through these, economic theory was consistently expanded beyond purchasing decisions to cover many aspects of human life, such as crime (Becker and Landes, 1974), politics (Persson and Tabellini, 2000; Mueller, 2003) and altruism (Fehr and Schmidt, 2006).

While the emphasis has been set on the theory's general explanatory power with respect to human behavior as a whole, demand analysis is still a central ground for testing the hypotheses on behavior's «congruence with reality»» (Stigler, 1950, p. 394). Several interesting empirical regularities show up in demand data and ought to be accounted for, even if new models must be conceived for the purpose. Modeling creativity spans the development of analytical models exhibiting both good data-fitting ability and theoretical consistency, the enrichment of the baseline framework with additional information such as the effects of education and other socioeconomic variables on preferences and the conception of preference dynamics through path-dependent consumption. Notwithstanding the significant improvements in the econometric analysis of consumption, the baseline theoretical framework often prevents a clear understanding of the forces driving behavior. This is especially troubling when the existing benchmark models are unable to *explain* known phenomena such as nonlinear Engel curves entailing different and varying demand-income elasticities.

In this paper we fill a gap in the literature by explicitly embedding into standard demand theory the psychological tenet of hierarchical needs. The model we develop is based on standard static constrained optimization yet is able to qualitatively reproduce some "stylized facts" of demand analysis, laying the ground for ordered elasticities to be based on ordered preferences. Furthermore, the model not only links economic and psychological evidence and theory as it yields an insightful understanding of differential satiation mechanisms without renouncing the analytical framework of constrained optimization.

The paper is outlined as follows: section 2 documents and discusses the empirical findings regarding the relation between income and demand; section 3 introduces the theoretical background for a needs-based approach; section 4 presents the main analytical results of this paper and section 5 discusses and illustrates these with a simple example where income elasticities vary with income; finally section 6 concludes the paper. Additional material is found in the appendices to the paper.

2. Engel Effects

2.1. Concepts and Evidence

> *the poorer a family, the greater the proportion of its total expenditure that must be devoted to the provision of food*
>
> (Engel, 1857, p. 28)

The statement above was made in 1857 by the statistician Ernst Engel while analyzing income and expenditure data for Belgian households. Though more a "stylized fact" than a "law", it was later coined "Engel's law", even if it was particularly weakly supported by Engel himself (Stigler, 1954, p. 98 ff.). There is some discussion about whether this assertion should be understood as directed to the behavior of aggregates or individuals. For instance, Chakrabarty and Hildenbrand (2011) consider Engel's statements as assertions on the joint distribution of income for a given population at a given moment in time and therefore not applicable to individual choice as described in microeconomic theory. At any rate, concepts are portable and past ideas can be associated with modern developments to produce a useful synthesis.

Two concepts closely related to this assertion are those of Engel curves and demand-income elasticity. The term "Engel curve" is used to denote «the function describing how a consumer's expenditures on some good or service relates to the consumer's total resources holding prices fixed» (Lewbel, 2008, p. 848).It is usually formulated as a functional dependence of demanded quantities, expenditure or budget shares on income. The concept can also refer to the empirical relation between different consumers' expenditures on a good and their income, also known as the *empirical/statistical* Engel curve (Lewbel, 2008, p. 848). Only in particular conditions would they would coincide – namely, when consumers face the same prices and having the same preferences – as aggregation can amplify or alter individual demand properties. Moreover, aggregation issues result not only from adding up different consumers but also from different goods: the empirical evidence shows that Engel curves over narrowly-defined goods vary strongly both across consumers and across time, while those reporting broad aggregates, though maybe including strongly heterogeneous goods, are much stabler (Lewbel 2008, p. 849; Chai and Moneta 2014, p. 313). Finally, at the highest level of aggregation, the Keynesian concept of marginal propensity to consume (Keynes, 1936, bk. III) is nothing by the slope of an Engel curve, i.e. $\text{MPC}_i = \frac{\partial x_i}{\partial y}$.

At the individual level the income elasticity of demand for good i is given by

$$\varepsilon_{y,i} = \frac{\partial x_i}{\partial y}\frac{y}{x_i} \tag{2.1}$$

and denotes how demand varies with changing income. More precisely, if the income elasticity for x_i is above 1, say 2, an increase of 1% in income will lead to a rise in the quantity bought of i of 2%, i.e. proportionally more than the income increase. Unless all income elasticities are unitary, demand patterns change with the level of income. Let good i's budget share – the fraction of income spent purchasing i – be denoted by w_i, where $w_i = \frac{p_i x_i}{y}$ with p_i the price of the good, x_i the quantity bought and y income. Then, the effect of income on the budget share of i is given by

$$\frac{\partial w_i}{\partial y} = -\frac{1}{y}w_i + \frac{p_i}{y}\frac{\partial x_i}{\partial y} = -\frac{1}{y}w_i + \frac{w_i}{y}\frac{\partial x_i}{\partial y}\frac{y}{x_i} = \frac{w_i}{y}(\varepsilon_{y,i} - 1) \tag{2.2}$$

Hence, if income elasticity is below (above) one, the budget share will decrease (increase) with rising income. If the income elasticity is positive but below one, the budget share will decrease even though expenditure increases. Furthermore, if some budget share increases, another must decrease as all must add to one (or 100%). The fact that with higher or lower income people buy different things – and even different kinds of things – has been recognized empirically ever since Engel's time: demand patterns do change with income. As Browning (2008, p. 850) claims,

> The widespread finding is that regressions of food expenditures, quantities or budget shares on income or total expenditures and other variables such as prices, demographics and regional dummies uniformly imply that the income elasticity of food is less than 1 (and greater than zero). For example, time series from individual countries, cross-sections within countries and cross-country analyses all find the same qualitative empirical finding

Many studies document that food budget shares decrease with income, having a positive but lower than one income elasticity[1]. Moreover, this finding is manifest even though the aggregate category "food" includes goods with very low and very high income elasticity (Lewbel, 2008)[2] and the usage of cross-country data does support its generality (Kaus, 2013, p. 123). There is also some evidence that clothing budget shares decrease with income, though not in a fully consistent pattern (Browning, 2008), while expenditure on recreation and culture is seen to rise with income (Kaus, 2013).

Another robust finding is that income elasticities can change with income, with some goods exhibiting high elasticities (e.g. above one) at low income levels which become smaller at high income levels (Lewbel 2008, p. 848; Lades 2013, p. 1024). The classical example, but not the only one, is again foodstuff: Blundell et al. (1993, p. 582) estimate income elasticities for food shrinking from about 0.8 for the bottom 5% of income distribution to less than 0.5 for the top 25%. Earlier evidence already supported the idea of income elasticities declining with income (Houthakker 1957, pp. 541-2, table II; Brown and Deaton 1972, p. 1173). In the light of these results, Moneta and Chai (2014, p. 898) explicitly claim that «a wide range of goods possess diminishing income elasticities», a claim that resonates with Keynes's (1936) insights on aggregate consumption. As pointed out by Blundell et al. (1993, p. 583), income elasticities can vary for different reasons, such as satiation or composition (changes in the specific goods acquired within a given category). While the possibility of satiation would induce decreasing income elasticity, changes in category composition could give rise to increasing income elasticity.

Some empirical models tried to address this issue in the past using either logarithmic (Working, 1943; Leser, 1963; Houthakker, 1957) or sigmoid functional forms (Prais, 1952; Aitchison and Brown, 1954). The latter class of models produce decreasing income elasticity with increasing income. Indeed, elasticity is driven down to zero when income goes to infinity (Aitchison and Brown, 1954, p. 38). However, full satiation does not occur, so this is not demand saturation – contrary to what Moneta and Chai (2014, p. 898) claim. Satiation is often connected with physiological needs (Witt, 2001; Moneta and Chai, 2014;

1. See, for example, Prais (1952); Prais and Houthakker (1955); Houthakker (1957); Houthakker (1961); Brown and Deaton (1972); Blundell et al. (1993); Banks et al. (1997); Seale and Regmi (2006); Chakrabarty and Hildenbrand (2011); Kaus (2013); Chai and Moneta (2010); Chai and Moneta (2012); Chai and Moneta (2014); Moneta and Chai (2014).

2. Lewbel (2008) actually mentions this fact to cast doubt on Engel's "law", but, contrariwise, it makes its robustness more remarkable still.

Lades, 2013), but, as Becker (1996, p. 3) argues, the kind of housing people want, their choices over leisure activities or even their diets have, for the average person, little to do with pressing biological constraints. Maslow (1943) makes a similar point, underlying that being hungry is not quite the same as undergoing hunger. If this does frustrate a purely physiological argument, it does not oppose the intuition underlying the thesis of satiation – and especially an ordered differential satiation of needs. Even if one has a limited want of quantities for a given class of goods, there may be an unlimited desire in improving quality (Marshall, 1920, III.II.1) and both can be subject to an ordering of needs.

2.2. Need for Theory

The empirical evidence reviewed above would have no great impact on theoretical models were it not for the fact that the most popular benchmarks are unable to account for nonlinear Engel curves. Here we detail some of these models and point out their shortcomings.

Arguably the most popular functional form to describe preferences is known by its acronym, CES, or constant elasticity of substitution function. As the limit cases it comprises evince, the CES function – first used by Solow (1956) and popularized by Arrow et al. (1961) – shows a great flexibility with varying a single parameter, encompassing the Leontief function (Dorfman, 2008) (perfect complements), the linear function (perfect substitutes) and all of those in between, including the Cobb-Douglas function (Cobb and Douglas, 1928) (independent goods). This "class" of functions was the main benchmark in applied research at least until the 1980s. For instance, the linear expenditure system, LES or Stone-Geary function (Geary, 1951; Stone, 1954), – derived from log Cobb-Douglas preferences with minimum quantities – has not only been a reference in applied work but also served as a framework for the inclusion of habits into demand functions (Pollak, 1970; Pollak and Wales, 1995). Also, the idea of nesting preferences using specific functionals was also developed within a LES-CES setting (Sato, 1967; Keller, 1976).

Though this class of preferences yield elegant Marshallian demand functions and indeed have been the main choice in much theoretical work, one of its major drawbacks is that it entails linear Engel curves, as demand depends linearly on income. This is due to these functional forms representing homothetic preferences, that is, positive monotonic transformations of linearly homogeneous functions. Homothetic preferences are such that, $x_i \succeq x_j \Rightarrow \lambda x_i \succeq \lambda x_j$, where x_i and x_j denote different goods and $\succeq$ indicates "preferred to" (Kreps, 2013, sec. 2.7). As homotheticity implies linearity in income (Gorman, 1961; Chipman, 1974), homothetic preferences in standard constrained optimization yield demand functions with unitary income elasticity. Thus, differences in income elasticity are often assumed to be due to changing 'tastes' (Browning, 2008, p. 851), a possibly negative spillover of the enduring homotheticity assumption.

The need to account for the empirically unavoidable nonlinearity of Engel curves led to log-demand models, known under the name of Working-Leser models (Working, 1943; Leser, 1963), but these were dropped for not being consistent with behavior optimization. Nevertheless they inspired the said "flexible" functional forms for demand systems. These tend to make use of the dual problem of consumer optimization to derive optimization-conforming models without imposing «strong and unwarranted restrictions on price elasticities» (Banks et al., 1997, p. 527). In particular,

> A demand system is said to be a "flexible functional form" if it is capable of providing a second order approximation to the behavior of any theoretically plausible demand system at a point in the price-expenditure space. More precisely, a flexible functional form can mimic not only the quantities demanded, the income derivatives, and the own-price derivatives, but also the cross-price derivatives at a particular point; equivalently, a flexible functional form can replicate not only the shares, the income elasticities, and the own-price elasticities, but also the cross-price elasticities at a specified price-expenditure situation (Pollak and Wales, 1995, p. 60)

Translog – transcendental logarithmic model (Jorgenson and Lau, 1975), AIDS (Deaton and Muellbauer, 1980a) – an almost ideal demand system – and QUAIDS (Banks et al., 1997), just to name a few examples, are fully flexible models, implying maximal data-fitting (and minimal explanatory power). AIDS gives the aggregation problem special attention: grounded in Muellbauer's (1976) extension to the Gorman polar form (Gorman, 1953, 1961), it relies on the price-independent generalized linear form (PIGL) of which its logarithmic limit, PIGLOG, is a special case. The model, then, enables exact aggregation «without invoking parallel linear Engel curves» (Deaton and Muellbauer, 1980a, p. 312). QUAIDS extends AIDS by adding a quadratic term of log income to it while retaining most of its properties. This enables direct estimation of nonlinearities in Engel curves.

Despite their appeal, these econometric models are not exempt from criticism. Paraphrasing Pollak and Wales (1995, pp. 64), these functional forms do avoid some restrictions in estimation, but must then introduce additional parameters or add other restrictions. Moreover, with the same number of parameters, a "nonflexible" functional form may approximate second order partial derivatives of the demand function with respect to own-price and expenditure by imposing constraints on the cross-price derivatives. In sum, Pollak and Wales (1995) argue that with an equal number of parameters there is no reason to think of these functions more "flexible" when compared to treating the consumer's problem from the primal approach, assuming a given objective function. Additionally, as the number of goods increases, the number of parameters to estimate increases exponentially, generating unbearable computational costs and possibly a loss in the precision of the results. In our view, although these models have recognizably expanded the quality of empirical estimations of demand systems, they were not conceived to address the question of why these nonlinear income effects exist. They are descriptive and not explanatory.

Finally, one interesting alternative is coined by Basmann et al. (2009) the Generalized Fechner-Thurstone (GFT) direct utility function. As these authors argue, complying with there being a preference ranking does not imply this to be dynamically stable nor that preferences are not influenced by prices nor income, besides other exogenous (to the optimization procedure) factors as education being able to impact the individual's utility function, that is, her reasons for behavior. The GFT model is then an adaptation of a Cobb-Douglas function where the exponents are made explicitly dependent on variables exogenous to the optimization. However, the model still merely attempts to fit budget share data using demographic and socio-economic variables other than quantities.

The persistence and robustness of varying income elasticities certainly begs the question of why there have been so few attempts to theoretically *explain* this phenomenon. Several economists have pointed out the need for theory to address these empirical regularities (Houthakker 1992, p. 219; Witt 2001, p. 24; Chai and Moneta 2010, p. 226; Lades 2013, p. 1025). In the words of Witt (2001, p. 24) «[c]hanging proportions in the demand for existing goods in a growing economy are attributed to the goods' income inferiority or superiority – begging the question of why the goods are considered inferior or superior». That is, while useful for empirical analysis, the lack of motivational content in functionals describing preferences also impairs the ability to understand changes in demand, constituting an obstacle to economics' explanatory and even predictive ability. As data is «intelligible only to the extent that it is interpreted with the help of a formal hypothesis that is imposed» (Phlips, 1983, p. 26), mere data fitting is deemed insufficient. Consequently, we argue that another class of preferences must be sought.

The plea for breaking the black-box status of preferences, endowing it with a needs-based «motivational approach» (Kaus, 2013, p. 118) has had a recent surge (Chai and Moneta, 2012; Moneta and Chai, 2014; Barigozzi and Moneta, 2016) as «deeper understanding of the motivations driving expenditure decisions may provide a proper foundation» for designing theoretically and empirically consistent demand systems (Chai and Moneta, 2010, p. 237). Over the next section, a review of needs-related literature ensues to discuss some concepts deemed relevant for economic theory.

3. Hierarchical structure of preferences

3.1. Needs in Economic Theory

Needs have appeared in economic theory more than once. Menger (1871), one of the forefathers of marginalism, understood economics as the theory concerned with human activity directed towards the satisfaction of needs (p. 48). A good, for Menger, is first and foremost something that serves to satisfy a «human need» and is recognized as such (Menger, 1871, I.1). He defined his concept of utility as «the capacity of a thing to serve for the satisfaction of human needs» Menger (1871, III.1).

It is significant that needs are absent from most theoretical discussions taking place in the first part of the 20th century, only to reappear linked to demand analysis as a way to explain empirical findings. For example, Houthakker's (1961, p. 726 ff.) notes that «useful insights» could be gained by looking at some goods from the point of view of the needs they satisfy, e.g. food and nutrition; though obviously the consumer does not value food solely from a nutritional perspective (Stigler, 1945).

In what respects existing models, Sen's (1985) and Nussbaum's (1987; 1988) capability approach would seem at first glance to provide a useful framework, given . its apparent conceptual similarity to motivational theories from psychology as well as its explicit reference to basic needs. Notwithstanding, although it has produced some portable concepts – such as the idea of conversion factors and functionings[3] – the capability

3. See Robeyns 2011; Nussbaum and Sen 1993 for a conceptual discussion and Sen 1985, pp. 7-10 for a formal setting.

approach lends itself better to welfare assessment (Basu and López-Calva, 2011; Herrero, 1996) than to embodying a theory on behavior and in fact was conceived for the former purpose and not the latter.

One of the few approaches to preferences which do make explicit claims regarding needs is that of lexicographic preferences – where we include closely related analytical frameworks such as Coursey's (1982; 1985). The basic principle supporting this approach is that needs, i.e. «something that it is universally necessary, for instance the need to eat» (p. 135), do exist and that when these are unsatisfied to some degree, no substitutability is possible. It is thus not uncommon to find statements against «unlimited preference substitutability» (Drakopoulos, 1994, pp. 133-4). The idea is that basic needs are addressed before any others, though the total absence of substitutability can be seen as even more extreme. In order to understand why, let us present a general lexicographic demand formulation (cf. Fishburn 1974; Martínez-Legaz 1999 for surveys):

Let $\mathbf{x}^a = (x_1^a, \ldots, x_n^a)$ and $\mathbf{x}^b = (x_1^b, \ldots, x_n^b)$ be two bundles. Within a lexicographic setting, $\mathbf{x}^a \succ \mathbf{x}^b$ (bundle a preferred to bundle b) implies $x_1^a > x_1^b$ or $x_i^a = x_i^b \wedge x_j^a > x_j^b$, $\forall i < j$, $\wedge i, j = \{1, \ldots, n\}$. Encarnación (1964), drawing on Georgescu-Roegen (1954), proposes that there might be a full-satiability threshold, x_i^*, which would allow for some "substitution". Then, $x^a \succ x^b$ iff $(x_1^* > x_1^a > x_1^b \vee x_1^a > x_1^* > x_1^b) \vee \big((x_i^* > x_i^a = x_i^b \vee x_i^a, x_i^b > x_i^*) \wedge (x_j^a > x_j^b)\big)$, $\forall i < j; i, j \in \{1, \ldots, n\}$. This formulation, however, still implies a strong ordering. Moreover, a piece is missing: what happens when all $x_i > x_i^*$? Some possibilities are: (i) the preference ordering acquires a "standard" character, (ii) the baseline lexicographic-choice algorithm from above comes back into action or, maybe, (iii) nirvana. Hypothesis (i) with x_i^* are the minimum survival needs would lead us to have *no* choice if $x_i < x_i^*$, since survival is obviously a "binding constraint" for there to be any choice at all. If x_i^* do not constitute minimum survival thresholds, then the strong ordering is too strong an assumption: we all need to eat, but also to drink. When above *survival* thresholds, there ought to be space for substituting across needs. Hypothesis (ii) is, following the prior discussion, even less credible, and discussion of (iii), as is customary to claim, is beyond the scope of this essay.

Regardless of the computational requirements it imposes and the incompatibility with most standard analytical methods, hierarchical choice still retains some appeal, especially in light of the traditional resistance to provide an explanation for empirical regularities. In the outdated words of Houthakker (1961, p. 726) «[t]he conventional theory is not interested in the origin of preferences, but only in their consistency. The explanation of such empirical phenomena as Engel's law is outside its scope». Such resistance led Drakopoulos (1994, p. 142) to claim that standard theory merely classifies goods according to their elasticities, but lacks «explanatory power» regarding the reasons behind this classification. A good example is Banks et al. (1997), which arrived at a model able to fit the data even in situations where some commodities seem to vary their income elasticities from above to below one with increasing income levels – a result that Drakopoulos (1994, p. 143) associated to hierarchical choice – yet the authors cast no light upon why this happens. Paradoxically, the implied strong hierarchical choice models oppose a clear treatment of the very income and substitution effects Drakopoulos argues they explain. In the words of Chai and Moneta (2012, p. 656), «what is lacking in this approach is any hard predictions about precisely what type of expenditures consumers are less willing to substitute at low levels of expenditure».

Finally, the "matching law" approach has been applied to demand models, where behavior is thought to adjust in order to equalize incentives (reinforcement returns, e.g. π_i) and costs (investment, c_i), such that

$$\frac{\pi_i}{\sum_{j=1}^{l} \pi_j} = \frac{c_i}{\sum_{j=1}^{l} c_j} \tag{2.1}$$

i.e. mean instead of marginal analysis (Herrnstein and Vaughan Jr., 1980; Herrnstein, 1990; Herrnstein and Prelec, 1991). A recent model based matching is Lades (2013), which stresses the difference between matching and optimization. While Lades (2013, p. 1026) argues that

> the neoclassical strategy to identify utility functions whose maximization leads to empirically testable demand functions was not particularly successful in offering an *explanation* for the described empirical regularities concerning Engel curves and income elasticities. In particular, the neoclassical approach has failed to explain why some goods are necessities and other goods are luxuries, and why income elasticities change with rising income in the way they do. The paper identifies two reasons for this: (1) the lack of a motivational foundation of utility functions, and (2) the pure

> focus on constrained utility maximization without acknowledging the possibility of other decision making processes

it should be clear by now that the standard approach can – and for some authors, including Becker (1996) and Rabin (2013), should – be enriched in order to expand its explanatory power. Thus, our approach is distinct from that of differential deprivation (Witt, 2001; Lades, 2013; Kaus, 2013), which recognizes that «[d]ifferences in the income elasticity of demand for the products that serve the different needs should express this differential satiation effect» yet does not explain hierarchy in need satisfaction. In combining economic and psychological insights on differential satiation mechanisms, our model does not do away with the standard analytical techniques based on constrained optimization.

Moreover, relying on optimization as a standard heuristic should not be seen necessarily as a drawback as it is known that any behavioral rule can be translated into an optimization problem – cf. Rabin 2013, p. 529, Stahl 2013. In sum, matching models of the type presented are not fully successful in their aims, not only because they are reducible to a constrained-optimization model – Lades's matching model can be given by a Cobb-Douglas behavior function with a Fechner-Thurstone flavor by defining one of the exponents as depending on income while retaining the other fixed – but mostly because these have the same shortcoming as other existing models: they are merely descriptive. Additionally, this model is too ad hoc in the way it relies on prices and income to change preferences. If preferences for a need or a good depend (more) positively on income (than others) this still does not *explain* why they do so.

3.2. Hierarchical Needs

The idea of a weak ordering of preferences underlying demand empirical facts was already present in Engel's work (1895) as he produced a needs-based classification of goods which he took to be crucial in explaining demand patterns. «Needs are not of the same rank», explains Engel: there are lower and higher needs and the greater the consumption possibilities the bigger the budget share associated to higher needs and – meeting Engel's "law" – the smaller the one directed towards satisfying lower needs, such as nourishing (*apud* Chai and Moneta, 2012, pp. 654-5). Consequently, Engel's studies on income can indeed be seen as an attempt to study household consumption patterns in relation to needs, and moreover, to a hierarchy of needs, examining how demand is affected by changes in income (Chai and Moneta, 2012, pp. 650-2). A deeper understanding of this phenomenon of preference ordering can be found within Maslovian psychology.

Maslow's (1943) seminal article provides a useful starting point for a needs-based account of preference theory. Maslow (1943, p. 370) posits that needs are ordered in a hierarchy of prepotency, where a person who is deprived of two needs will, *ceteris paribus*, tend to satisfy the lower need, the more prepotent, first.

Technically, this implies that Inada conditions (Inada, 1963; Uzawa, 1963), when present in behavior functions, will provide an insufficient description of behavior, as these conditions imply that $\forall i$ (possibly subject to $\forall j \neq i\,, x_j > 0$),

$$\lim_{x_i \to 0} \frac{\partial B}{\partial x_i} = +\infty \tag{2.2}$$

where x_i denotes a given need and B the behavior constrained-optimization objective function. In contrast, Maslow's account of ordered needs would include an important refinement, where if two needs (or two goods that exclusively serve these needs) tend to zero (complete deprivation), one of them, the lower, would be fully dominant, i.e., subject to $\forall j < i$, $x_j > 0$,

$$\lim_{\substack{x_i \to 0 \\ x_{i+m} \to 0}} \frac{\partial B}{\partial x_i} > \lim_{\substack{x_i \to 0 \\ x_{i+m} \to 0}} \frac{\partial B}{\partial x_{i+m}} = 0 \tag{2.3}$$

This, in turn, implies that a given need becomes pressing only after lower-order needs have been satisfied (Maslow, 1943, p. 370). As Jevons (1871, ch. III, p. 54) pointed out many years earlier, this does not mean that «the satisfaction of a lower want creates a higher want; it merely permits the higher want to manifest itself».

Need satiation in this context appears in neither a strong lexicographical manner nor a binary form. Instead, needs are satisfied to different degrees, with the prepotency of a given need given by how satisfied it is *and* by how satisfied are all the lower-order needs. The ordering is smooth and not strong – here a lengthier quote is due, as the opposite is usually thought of Maslow's "hierarchy of needs":

> We have spoken in such terms as the following: "If one need is satisfied, then another emerges." This statement might give the false impression that a need must be satisfied 100 per cent before the next need emerges. In fact, most members of our

> society who are normal, are partially satisfied in all their basic needs and partially unsatisfied in all their basic needs at the same time. A more realistic description of the hierarchy would be in terms of decreasing percentages of satisfaction as we go up the hierarchy of prepotency. (. . .) As for the concept of emergence of a new need after satisfaction of the prepotent need, this emergence is not a sudden, saltatory phenomenon but rather a gradual emergence by slow degrees from nothingness. For instance, if prepotent need A is satisfied only 10 per cent then need B may not be visible at all. However, as this need A becomes satisfied 25 per cent, need B may emerge 5 per cent, as need A becomes satisfied 75 per cent need B may emerge 90 per cent, and so on. (Maslow, 1987, pp. 53-4)

Individuals will be «partially satisfied and partially unsatisfied» in all their needs and the ordering will then be on the level of the needs' prepotency (Maslow, 1943, p. 395).

Lower needs would then be those closer to basic needs (Maslow, 1943, p. 384); and, within basic needs, physiological/survival would be the lowest-order ones since, when everything is lacking, they are more acutely felt (Maslow 1943, p. 373; Maslow 1987, pp. 36-7). Nevertheless, similarly to Becker (1996, p. 3), Maslow (1987, p. 38) also considers that too much attention has been given to physiological needs as *extreme* deprivation is rare in contemporary society and most behavior cannot then be overdetermined by physiological needs. If needs can account for behavior, these are not subsumed to the lowest order needs.

Needs-based theories tend to assume a universally shared set of needs (Maslow 1943, p. 389; Tay and Diener 2011, p. 354), what some might consider problematic. However, as Stigler and Becker (1977, p. 89) assert, no relevant behavior has been better explained by simply positing a difference in the structure of preferences across different persons (and time), «[t]hey give the appearance of considered judgement, yet really have only been ad hoc arguments that disguise analytical failures». Note that – oppositely to what is the common interpretation, e.g. Pollak and Wales (1995, p. 124) – this does not mean that people do act the same, but that perhaps one could better understand the differences across different persons' preferences through a general function that takes into account each person's "stocks of personal capital", exposure or, we might add, needs-satisfaction, i.e. their history and situation. In other words, preferences are endogenous and – against Friedman (1962, p. 13) and Houthakker (1961, p. 733) – preference formation *is* a matter of study for economics. Analogously, Alderfer (1977, p. 661) asserts that «[a]ssuming all people have certain needs does not assume all people have the same strength of all needs. Need theory does not contradict the principles of individual differences. If anything, it enhances the understanding of individual differences by specifying some conditions that explain how individuals evolve their differences in need strength».

Recent empirical evidence from psychology[4] lends some support to the thesis of an ordering of needs. In particular, Tay and Diener (2011) use Gallup World Poll data on 123 countries to test the adequacy of the hierarchical Maslovian framework as an explanation of self-reported need satisfaction. Through a multilevel item-response model, these authors found that need satisfaction seems to be a necessary but not sufficient condition for subjective well-being (SWB), with negative feelings being associated to deprivation of lower needs – relying substantially on societal conditions – and positive ones to «psychosocial needs», linked to a greater extent to personal factors (Tay and Diener, 2011, pp. 359, 363). Furthermore, different needs are more closely associated to different SWB "components", and they are ordered: «needs emerged to some degree in an order that would be suggested by Maslow's ordering, especially for individuals who have lower total needs fulfilled», though the fulfillment of these seemed to depend to a larger extent on country-level conditions (Tay and Diener, 2011, p. 361). In sum, the authors «found evidence of universality and also substantial independence in the effects of the needs on SWB [subjective well-being]» (Tay and Diener, 2011, p. 364).

In applying a needs-based theoretical framework to demand analysis, some difficulties are immediately perceivable, the most relevant of which is the detailing of *a* hierarchy of needs. Maslow's theory is mostly known for the specific "list" of needs he hypothesized and many other proposals have been put forward, both before (Engel, 1895) and after (e.g. Alderfer, 1969; Galtung, 1980; Deci and Ryan, 2000) Maslow's, even combining Maslow's insights with evolutionary psychology (Kenrick et al., 2010; Bernard et al., 2005). Which one is the most relevant is arguably a legitimate question – though the mere quest for *the* list of needs was much criticized by Maslow (1943, pp. 370-1; 1987, pp. 25-6) himself – but the fact that no "ultimate needs list" is consensual should not divert our

4. Early empirical examination of Maslow's theory (Wahba and Bridwell, 1976) was rather flawed and results were particularly ambiguous. It did not take into account that Maslow's theory is not about a fixed ranking of importance given and recognized to each need, but about behavior (a critique maybe alike to those who claim reported subjective well-being is not the same as happiness).

attention from the tenet of an ordering in needs. Finally, the idea of an ordering in terms of income elasticity also appears in the literature related to other classification schemes, namely related to "differential arousement" (Scitovsky, 1992) and "defensive" and "creative" products (Hawtrey, 1925; Scitovsky, 1992), so a flexible ordered preference *structure* might serve other modeling purposes as well.

4. A New Class of Ordered Preferences and a Needs-Based Model

the theory of Economics must begin with a correct theory of consumption

(Jevons, 1871, ch. III, p. 40)

In this section we provide a general model of consumer behavior that is based on ordered needs. Following a Littleian (Little, 1949, p. 90) tradition, the objective function of the consumer's constrained optimization problem is termed "behavior function" and, thus, denoted by a B – see appendix 2.B. for a more detailed discussion. B is assumed to describe preferences, here understood as "reasons for behavior" (Bowles, 2004, pp. 99-100).

4.1. Definitions

It will be convenient to define σ_i as the degree of satisfaction of a given individual in respect to need i, where satiation of a need i depends on x_i, which might be the consumption of a given good or bundle of goods, and each good/bundle serves to satisfy one single need. In particular, let σ_i denote a function $\mathbb{R}_+ \to \mathbb{R}_+$ taking x_i as an argument[5], where

$$\sigma_i(x_i) \geq 0 \tag{2.1}$$

$$\sigma_i(x_i) \in C^2 \tag{2.2}$$

$$x_i > 0 \Rightarrow \sigma_i(x_i) > 0 \tag{2.3}$$

$$\sigma_i(0) = 0 \tag{2.4}$$

$$\frac{d\sigma_i}{dx_i} > 0 \tag{2.5}$$

$$\frac{d^2\sigma_i}{(dx_i)^2} \leq 0 \tag{2.6}$$

5. In order to rejoin the psychological theory presented above, the range of the function could be bounded, with the case of $\sigma_i \in [0, 1]$ representing the natural bounds denoting full satiation and complete deprivation. However, for the purposes of this section, bounds will not be imposed.

A useful functional representation of ordered preferences based on σ_i is given by the non-homothetic function

$$B(\mathbf{x}) = \sigma_1(x_1) + \sigma_1(x_1)\sigma_2(x_2) + ... + \sigma_1(x_1)\sigma_2(x_2)\cdots\sigma_{l-1}(x_{l-1})\sigma_l(x_l) = \sum_{j=1}^{l}\prod_{h=1}^{j}\sigma_h(x_h) \tag{2.7}$$

where $B \in C^3$ and, naturally, $B : \mathbb{R}^l_+ \to \mathbb{R}_+$ and assumed to be quasiconcave. Additionally, it is straightforward to see that if the σ_i are bounded, B will be bounded as well.

For convenience, let us describe B as

$$B(\mathbf{x}) = b_1 = \sigma_1(x_1) + b_2 = \sigma_1(x_1) + \sigma_1(x_1)\sigma_2(x_2) + b_3 = \text{etc.} \tag{2.8}$$

where each b_i, $i = 2, 3, .., l-1$, can be written as

$$b_i = \left(\prod_{h=1}^{i-1}\sigma_h\right)\sigma_i + b_{i+1} = \left(\prod_{h=1}^{i-1}\sigma_h\right)\sigma_i\left(1 + \sum_{j=i+1}^{l}\prod_{k=i+1}^{j}\sigma_k\right) \tag{2.9}$$

Then, one has

$$\frac{b_{i+1}}{b_i} = \frac{\sigma_{i+1}\left(1 + \sum_{j=i+2}^{l}\prod_{k=i+2}^{j}\sigma_k\right)}{1 + \sigma_{i+1}\left(1 + \sum_{j=i+2}^{l}\prod_{k=i+2}^{j}\sigma_k\right)} \tag{2.10}$$

It is then clear that

$$b_i \geq b_{i+m} \geq 0 \tag{2.11}$$

$$\frac{\partial \frac{b_{i+1}}{b_i}}{\partial x_i} = 0 \tag{2.12}$$

4.2. Constrained Optimization

As (assumed) quasi-concavity of B implies that preferences are convex (Kreps, 2013, sec. 2.2), and given that B is defined over the nonnegative orthant, the problem described by

$$\begin{aligned} &\max_{\mathbf{x}} \quad B \\ &\text{s.t.} \;\; \mathbf{p} \cdot \mathbf{x} \leq y \\ &\qquad \mathbf{x} \geq \mathbf{0} \qquad \mathbf{p} \gg \mathbf{0} \\ &\qquad y > 0 \end{aligned} \tag{2.13}$$

is amenable to quasiconcave programming conditions according to the Arrow-Enthoven sufficiency theorem (Arrow and Enthoven, 1961). As the constraint is linear, the constraint qualification is satisfied and Karush-Kuhn-Tucker conditions are both sufficient and necessary for a global optimum (Chiang and Wainwright, 2005, 424 ff.). Moreover, for positive income, as the objective function is strictly increasing, the budget constraint is binding at the optimum. The solution to this problem is given by the first-order conditions (FOC)

$$\frac{\partial B}{\partial x_i} - p_i \lambda \leq 0\,, \qquad x_i \geq 0\,, \qquad x_i \left(\frac{\partial B}{\partial x_i} - p_i \lambda \right) = 0 \tag{2.14}$$

$$y - \mathbf{p} \cdot \mathbf{x} = 0\,, \qquad \lambda > 0 \tag{2.15}$$

with $i = 1, 2, ..., l$.

For any two x_i, x_{i+1}, the FOC imply

$$\frac{d\sigma_i}{dx_i} \frac{1}{\sigma_i} b_i \frac{1}{p_i} \geq \frac{d\sigma_{i+1}}{dx_{i+1}} \frac{1}{\sigma_{i+1}} b_{i+1} \frac{1}{p_{i+1}} \tag{2.16}$$

Proposition 2.1. *With positive income and prices there is at least one need for which the degree of satisfaction is not zero.*

Or, more generally, $y > 0 \wedge \mathbf{p} \gg \mathbf{0} \;\Rightarrow\; \exists^1 \, i : \, \sigma_i > 0$.

Proof. Define[6]

$$\begin{aligned} \boldsymbol{\sigma}^*(\mathbf{x}^*) = \arg\max_{\mathbf{x}} \quad & B \\ \text{s.t.} \quad & \mathbf{p}\cdot\mathbf{x} = y \end{aligned} \tag{2.17}$$

As B is increasing in its arguments and strictly increasing in x_1 (unconditionally) and in all x_i, $i : \forall x_{j<i} > 0$, then the constraint will be met with equality and it must be the case that $\mathbf{x}^* \geq 0 \Rightarrow \boldsymbol{\sigma}^* \geq 0$ with $\exists^1\, i :\ x_i^* > 0 \Rightarrow \exists^1\, i :\ \sigma_i^* > 0$. □

Proposition 2.2. *If a given need remains in complete deprivation at the optimum, higher needs will too.*

That is, if $x_i = 0$, then $x_{i+m} = 0$, $\forall\ m = 1, ..., l - i$.

Proof. Notice that $\sigma_i^* \Rightarrow \sigma_{i+m}^* = 0$, given that $B(\boldsymbol{\sigma}|\sigma_i = 0) = B(\boldsymbol{\sigma}|\sigma_i = \sigma_{i+m} = 0)$, $\forall\, m = 1, ..., l - i$, which in turn implies that $\boldsymbol{\sigma}^*(\mathbf{x}^*) = \arg\max_{\mathbf{x}} B(\boldsymbol{\sigma}|\sigma_i = 0)$ s.t. $\mathbf{p}\cdot\mathbf{x} = y$ $\Leftrightarrow \boldsymbol{\sigma}^*(\mathbf{x}^*) = \arg\max_{\mathbf{x}} B(\boldsymbol{\sigma}|\sigma_i = \sigma_{i+m} = 0)$ s.t. $\mathbf{p}\cdot\mathbf{x} = y$. Thus, if $\sigma_i^* = 0$, increasing σ_{i+m}^* will not increase B. □

Proposition 2.3. *It is possible that some needs are not satisfied at all.*

In other words, this setting *can admit* boundary cases such that $x_j > 0$, $\forall\, j = 1, ..., i-1$; $x_i > 0$, $x_{i+1} = x_{i+2} = \cdots = x_l = 0$.

Proof. From eq. 2.16, the case where need i is satisfied in some degree – which implies all lower ones are also – but need $i+1$ is not is given by
(we will henceforth drop the asterisk to ease the notation)

$$\begin{aligned} &\prod_{h=1}^{i-1} \sigma_h \frac{d\sigma_i}{dx_i} \left[1 + \sigma_{i+1}|_{x_{i+1}=0} \left(1 + \sum_{j=i+2}^{l} \prod_{k=i+2}^{j} \sigma_k \right) \right] \frac{1}{p_i} \geq \\ &\qquad \geq \prod_{h=1}^{i-1} \sigma_h \sigma_i \left.\frac{d\sigma_{i+1}}{dx_{i+1}}\right|_{x_{i+1}=0} \left(1 + \sum_{j=i+2}^{l} \prod_{k=i+2}^{j} \sigma_k \Big|_{x_k=0} \right) \frac{1}{p_{i+1}} \Leftrightarrow \end{aligned} \tag{2.18}$$

6. Positive prices, income and non-negative quantities will be assumed throughout.

$$\Leftrightarrow \frac{d\sigma_i}{dx_i}\frac{1}{\sigma_i}\frac{1}{p_i} \geq \left.\frac{d\sigma_{i+1}}{dx_{i+1}}\right|_{x_{i+1}=0}\frac{1}{p_{i+1}} \tag{2.19}$$

It then suffices that the derivative of σ_{i+1} wrt. x_{i+1} be defined when x_{i+1} is zero, i.e.

$$\left.\frac{d\sigma_{i+1}}{dx_{i+1}}\right|_{x_{i+1}=0} \in (0\,,\,+\infty) \tag{2.20}$$

as when $x_i \to 0 \;\Rightarrow\; \sigma_i \to 0$, the left-hand side of the inequality will tend to infinity. Thus $x_{i+1} > 0$ iff x_i is sufficiently great. □

In plainer terms, these preferences imply that if a need i is not satisfied up to some degree, $i+1$ will not be satisfied at all, nor will any of the higher order needs.

Proposition 2.4. *All needs can be met to some degree.*

Both boundary situations and an interior equilibrium are possible. In the latter, eq. 2.16 will be met with an equality.

$$\frac{d\sigma_i}{dx_i}\frac{1}{\sigma_i}\frac{b_i}{b_{i+1}}\frac{p_{i+1}}{p_i} = \frac{d\sigma_{i+1}}{dx_{i+1}}\frac{1}{\sigma_{i+1}} \tag{2.21}$$

Proposition 2.5. *The growth in satiation per additional monetary unit spent is higher in higher needs than in lower ones.*

Proof. In a case where there is an interior equilibrium, from eq. 2.21 we have

$$\frac{\frac{d\sigma_{i+1}}{dx_{i+1}}}{\sigma_{i+1}}\frac{1}{p_{i+1}} = \frac{\frac{d\sigma_i}{dx_i}}{\sigma_i}\frac{1}{p_i}\frac{b_i}{b_{i+1}} > \frac{\frac{d\sigma_i}{dx_i}}{\sigma_i}\frac{1}{p_i} \tag{2.22}$$

Denoting the growth rate of satiation in need i by g_{σ_i},

$$\frac{d\sigma_i}{\sigma_i} \approx g_{\sigma_i} \tag{2.23}$$

Now, holding prices fixed, we have

$$p_i dx_i = de_i \approx \Delta e_i \tag{2.24}$$

where e_i denotes expenditure in goods related with need i.

Then, as

$$\frac{\frac{d\sigma_i}{dx_i}}{\sigma_i}\frac{1}{p_i} \approx \frac{g_{\sigma_i}}{\Delta e_i} \tag{2.25}$$

the first-order conditions themselves imply that, at the optimal point, higher needs will exhibit a higher growth rate of satiation per increase in expenditure, when holding prices fixed. □

4.3. Ordered Satiation, Income Elasticities and Budget Shares

In this section we will assess the implications for our results of some of the hypotheses that have been brought forth in the previous literature. We will start by exploring the implications of two conditions on satiation inspired by the work of Maslow. All results are subject to the optimization program and assuming that some quantity of x_i and x_{i+1} is indeed purchased, i.e. eq. 2.21.

Maslow's Condition (MC). *At the optimum, satiation will be decreasing in the order of needs.*

$$\sigma_i \geq \sigma_{i+1} \tag{2.26}$$

Following Maslow's condition, a reasonable condition is that differential satiation is higher in higher needs, given that these are less satisfied. Consequently, the increase in higher needs satiation can be thought to be greater in marginal terms. Formally, one has,

Differential Satiation Condition (DSC). *At the optimum, differential satiation will be lower in lower needs.*

$$\frac{d\sigma_{i+1}}{dx_{i+1}} \geq \frac{d\sigma_i}{dx_i} \tag{2.27}$$

A first look at MC and DSC shows that this requires some ordering in prices, as, from the interior equilibrium condition

$$\frac{d\sigma_i}{dx_i}\frac{1}{\sigma_i}\frac{b_i}{b_{i+1}}\frac{p_{i+1}}{p_i} = \frac{d\sigma_{i+1}}{dx_{i+1}}\frac{1}{\sigma_{i+1}} \Leftrightarrow \frac{\frac{d\sigma_{i+1}}{dx_{i+1}}}{\frac{d\sigma_i}{dx_i}}\frac{\sigma_i}{\sigma_{i+1}} = \frac{b_i}{b_{i+1}}\frac{p_{i+1}}{p_i} \geq 1 \Leftrightarrow \frac{p_{i+1}}{p_i} \geq \frac{b_{i+1}}{b_i} \tag{2.28}$$

That is, p_{i+1} must be higher enough relative to p_i in order for MC and DSC to be verified.

A more attentive observation can lead us to the following proposition:

Proposition 2.6. *Maslow's Condition and Differential Satiation Condition together imply that greater quantities will be consumed to satiate lower needs than higher ones.*

Proof. As, at the optimum, the first-order conditions define an implicit function with x_{i+1} depending on x_i (or vice-versa), differentiating both sides of MC wrt. x_i, one has

$$\frac{d\sigma_i}{dx_i} \geq \frac{d\sigma_{i+1}}{dx_{i+1}}\frac{dx_{i+1}}{dx_i} \tag{2.29}$$

what, coupled with DSC, yields

$$\frac{d\sigma_{i+1}}{dx_{i+1}} \geq \frac{d\sigma_i}{dx_i} \geq 1 \geq \frac{\frac{d\sigma_i}{dx_i}}{\frac{d\sigma_{i+1}}{dx_{i+1}}} \geq \frac{dx_{i+1}}{dx_i} \Rightarrow 1 \geq \frac{dx_{i+1}}{dx_i} \tag{2.30}$$

Suppose $x_{i+1} \geq x_i$. Then,

$$\frac{dx_{i+1}}{dx_i} \geq 1 \tag{2.31}$$

which contradicts eq. 2.30. This concludes the proof. □

Another empirically relevant issue, considering the literature, is the analysis of income elasticities. In particular, one can suggest that income elasticities would be ordered in the same way as needs are, so that the consumption of goods associated with lower-order needs reacts less to income than that of goods of higher-order needs. As noted in section 2.2

most theoretical models resort to homothetic preferences, implying unit income elasticities for all goods, and therefore cannot give rise to ordered income elasticities. Formally, we wish to assess the conditions under which ordered income elasticities might appear.

Ordered Income Elasticities Condition (OIEC). *Income elasticities are increasing in the order of needs.*

Let income elasticity of the good/bundle associated to need i be denoted by $\varepsilon_{y,i}$. Then,

$$\varepsilon_{y,i} \leq \varepsilon_{y,i+1} \Leftrightarrow \frac{\partial x_i}{\partial y}\frac{y}{x_i} \leq \frac{\partial x_{i+1}}{\partial y}\frac{y}{x_{i+1}} = \frac{dx_{i+1}}{dx_i}\frac{\partial x_i}{\partial y}\frac{y}{x_{i+1}} \Leftrightarrow \tag{2.32}$$

$$\Leftrightarrow \frac{x_{i+1}}{x_i} \leq \frac{dx_{i+1}}{dx_i} \tag{2.33}$$

This implies that, in order to have $\varepsilon_{y,i} \neq \varepsilon_{y,i+1}$ it is necessary for $\frac{dx_{i+1}}{dx_i}$ not to depend on any x_j, i.e.

$$\varepsilon_{y,i} \neq \varepsilon_{y,i+1} \Rightarrow \nexists^1 x_j \in \mathbf{x} : \frac{d\frac{dx_{i+1}}{dx_i}}{dx_j} \neq 0 \tag{2.34}$$

It is now possible to see if Maslovian Ordered Satiation (as described in MC) holds and income elasticities are ordered, there will also be an order in budget shares. Differentiating both sides of the inequality given by MC wrt. x_i and combining MC and OIEC, one has necessarily has

$$\frac{\frac{d\sigma_i}{dx_i}}{\frac{d\sigma_{i+1}}{dx_{i+1}}} \geq \frac{dx_{i+1}}{dx_i} \geq \frac{x_{i+1}}{x_i} \tag{2.35}$$

From eq. 2.21, an interior equilibrium is defined as

$$\frac{\sigma_i}{\sigma_{i+1}} = \frac{\frac{d\sigma_i}{dx_i}}{\frac{d\sigma_{i+1}}{dx_{i+1}}}\frac{p_{i+1}}{p_i}\frac{b_i}{b_{i+1}} \tag{2.36}$$

Imposing MC and OIEC, one obtains

$$\frac{\sigma_i}{\sigma_{i+1}} = \frac{\frac{d\sigma_i}{dx_i}}{\frac{d\sigma_{i+1}}{dx_{i+1}}}\frac{p_{i+1}}{p_i}\frac{b_i}{b_{i+1}} > \frac{\frac{d\sigma_i}{dx_i}}{\frac{d\sigma_{i+1}}{dx_{i+1}}}\frac{p_{i+1}}{p_i} \geq \frac{x_{i+1}}{x_i}\frac{p_{i+1}}{p_i} \geq \frac{p_{i+1}x_{i+1}}{p_i x_i} \Leftrightarrow \tag{2.37}$$

$$\Leftrightarrow \frac{\sigma_i}{\sigma_{i+1}} > \frac{w_{i+1}}{w_i} \tag{2.38}$$

which imposes an order on the budget share: only if the consumer is sufficiently satiated in lower needs will the budget share allocated to higher needs be greater than the one directed to satisfy lower ones. This result, however, does not constrain the relative size of budget shares, i.e. $\frac{w_{i+1}}{w_i} \gtreqless 1$.

4.4. Nested Needs

We will now turn our attention to a subclass of this structure of preferences. Assume that there are only two needs, a lower (1) and a higher (2) one. Then our function simplifies to

$$B(x_1, x_2) = \sigma_1(x_1) + \sigma_1(x_1)\sigma_2(x_2) = \sigma_1(x_1)(1 + \sigma_2(x_2)) \tag{2.39}$$

It is straightforward to see that if $\sigma_i(x_i)$ are concave, $i = 1, 2$, – as assumed in section 4.1 – $B : \mathbb{R}^2_+ \to \mathbb{R}_+$, is log-concave.

Consider the case where $x_1 = f_1(x_{11}, x_{12})$, $f_1 : \mathbb{R}^2_+ \to \mathbb{R}_+$ and f_1 is log-concave. Then, B is still log-concave in $\mathbf{x} = (x_{11}, x_{12}, x_2)$. The reasoning could continue indefinitely, with each x_ij being in turn given by a concave function of more disaggregate bundles of goods and still B would retain log-concavity. Thus, an ordering of more specific "sub-needs" can be defined within each lower need by decomposing each need into concave functions of different needs. The higher need at each level can also be decomposed into "sub-needs", but to *assure* the quasiconcavity of B – by assuring log-concavity – we require that the higher need at each level be given by *concave* function of "sub-needs". This reasoning allows that B be weakly separable in needs while becoming amenable to a clearer analytical treatment. Also, it shows that this structure can nest familiar behavior functions at ease.

We will now present some additional propositions. Specifically, we assert the general condition (necessary and sufficient) for ordered income elasticities to arise in this class of preferences model for two sub-needs, goods or bundles – a lower (1) and a higher one (2) – and a sufficiency one that will simplify the discussion. As the proof is quite long, it will be left as an appendix to the paper.

Proposition 2.7. *If* $\varepsilon_{\sigma_1} - \varepsilon^{(2)}_{\sigma_1} \geq \varepsilon_{\sigma_2} - \varepsilon^{(2)}_{\sigma_2} - \left(1 - \frac{b_2}{b_1}\right)\varepsilon_{\sigma_2}$, *then the Ordered Income Elasticities Condition is met and income elasticity of demand will be ordered as needs.*

Proposition 2.8. *It is sufficient that* $\varepsilon_{\sigma_1} - \varepsilon_{\sigma_1}^{(2)} \geq \varepsilon_{\sigma_2} - \varepsilon_{\sigma_2}^{(2)}$*, for income elasticity of demand to be ordered as needs.*

where $\varepsilon_{\sigma_i} = \frac{d\sigma_i}{dx_i}\frac{x_i}{\sigma_i}$ and $\varepsilon_{\sigma_i}^{(2)} = \frac{d^2\sigma_i}{(dx_i)^2}\frac{x_i}{d\sigma_i/dx_i}$.

Upon a first glance, these conditions may seem quite esoteric . However, from this we can state the following remark:

Remark 2.9. *If each* σ_i *is given by an homogeneous function, income elasticities will be ordered.*

Proof. As, for any homogeneous function, $\varepsilon_\sigma - \varepsilon_{\sigma_i}^{(2)} = 1$, $\varepsilon_{\sigma_1} - \varepsilon_{\sigma_1}^{(2)} = \varepsilon_{\sigma_2} - \varepsilon_{\sigma_2}^{(2)}$ and the sufficiency condition given in proposition 2.8 is met. □

Proposition 2.8 is also useful for another class of satiation functions, where satiation is bounded between 0 (full deprivation) and 1 (complete saturation). In particular,

$$\sigma_i(x_i) = \frac{\alpha_i x_i}{1 + \alpha_i x_i}, \quad \alpha_i > 0 \tag{2.40}$$

Let us coin this class of functions as *sigmoid satiation functions*. This functional form allows for interior equilibria and boundary situations where some of the higher needs are not met at all, while complying with all the requirements in section 4.1. The conditions for these functions to show ordered income elasticities is given by:

Remark 2.10. *If each* σ_i *is given by a sigmoid satiation function (eq. 2.40) , income elasticities will be ordered whenever* $\alpha_1/\alpha_2 \geq x_2/x_1$.

Proof. As $\varepsilon_{\sigma_i} - \varepsilon_{\sigma_i}^{(2)} = 2 - (1 + \alpha_i x_i)^{-1}$, $2 - (1 + \alpha_1 x_1)^{-1} \geq 2 - (1 + \alpha_2 x_2)^{-1} \Leftrightarrow \frac{\alpha_1}{\alpha_2} \geq \frac{x_2}{x_1}$, for $x_1 > 0$ and $x_2 \geq 0$. □

The condition is then sufficient, not necessary. Moreover, this implies that if $\alpha_1 \geq \alpha_2$, whenever MC and DSC are met, income elasticities are ordered such that $\varepsilon_{y,1} < \varepsilon_{y,2}$.

For the purpose of this paper, we will focus on subdividing lower needs only. This implies

$$B(\mathbf{x}) = S_l(S_{l-1}, x_l) = S_{1-1}(S_{l-2}, x_{l-1})(1 + \sigma_l(x_l)) \tag{2.41}$$

$$S_i(S_{i-1}, x_i) = S_{i-1}(S_{i-2}, x_{i-1})(1 + \sigma_i(x_i))\,, \quad i = 2, 3, ..., l \tag{2.42}$$

$$S_1(x_1) = \sigma_1(x_1) \tag{2.43}$$

There are three caveats regarding this structure: (i) strong nonlinearities may prevent closed form solutions when the number of needs involved is high; (ii) the possibility of boundary conditions implies that the computational requirement to solve the model increase exponentially with the number of needs; and (iii) the fact that each level is non-homothetic implies that no exact price aggregator – depending only on prices – can be found. That being said, it does cast some light in how the standard demand theory can be embedded in a needs-based framework to explain existing demand patterns, as it will be illustrated in the following section.

5. Discussion

The previous section showed that the structure of non-homothetic preferences we propose is analytically tractable. It can imply an ordering of goods either in terms of income elasticities, "differential" satisfaction or both, as will be shown in the following section by assuming a specific function for σ_i and detailing the results. Following the presentation of this general class of preferences, a specific illustration is in order. Its implications, namely of nonsaturation of demand, nonlinearities, effects of prices on budget shares, and its ability to model need satisfaction (the σs) depending on several goods will be discussed in the current section[7]

5.1. A "two-needs" example

In this section we will assume a sigmoid satisfaction function given by

$$\sigma_i(x_i) = \frac{x_i}{1 + x_i}\,, \quad i = 1, 2 \tag{2.1}$$

7. Additional remarks on the behavior function are collected in appendix 2.C.

with the behavior function defined as above:

$$B(x_1, x_2) = \sigma_1(x_1) + \sigma_1(x_1)\sigma_2(x_2) \tag{2.2}$$

Notice that $\sigma_i(x_i) \in [0, 1)$, with $\lim_{x_i \to +\infty} = 1$ and, consequently, $B \in [0, 2)$.

The solution for the constrained optimization problem follows the definitions given above – the specific functions for demand (and others from there derived) are given in the digital appendices that complement this paper. The example itself will be used as illustrating the discussion of the results, where the graphs assume that $p_1 = 1$, $p_2 = 8$ and $y = 24$ whenever these are held fixed.

5.2. Ordered Preferences and Ordered Elasticities

Figure 2.1: **Behavior Lines**

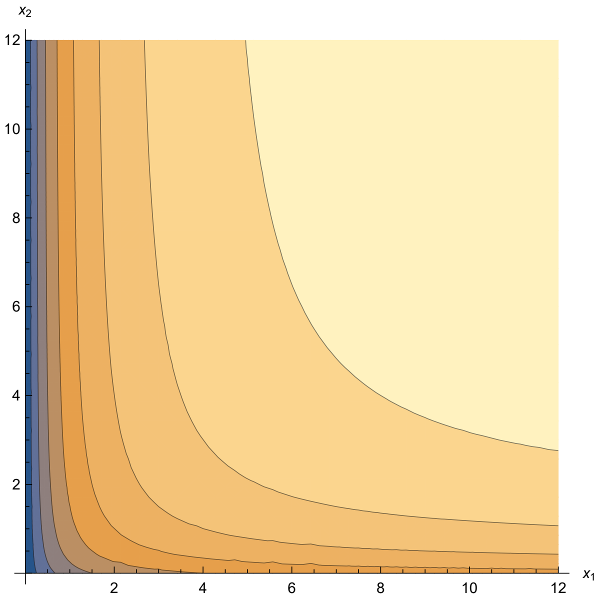
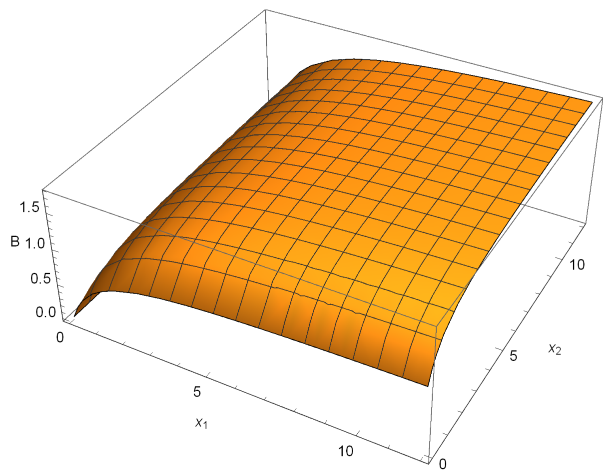


Figure 2.2: **Behavior Function**



Preferences, as shown in fig. 2.1 are well behaved: convex, with positive first-order derivatives and non-positive second-order derivatives with respect to each good. However, interestingly, the graphical representation clearly suggests a *weakly* lexicographical shape, as only after a given amount of x_1 does B increase significantly with increases in x_2. And it also allows $B(x_1, x_2 | x_2 = 0) > 0$, as can be seen in fig. 2.2, while not the converse.

Figure 2.3: **Satiation**

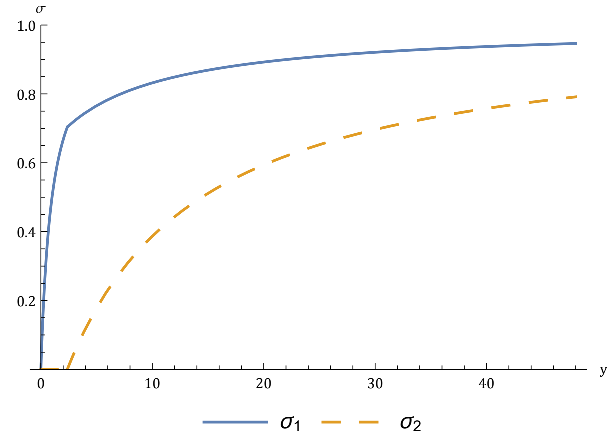
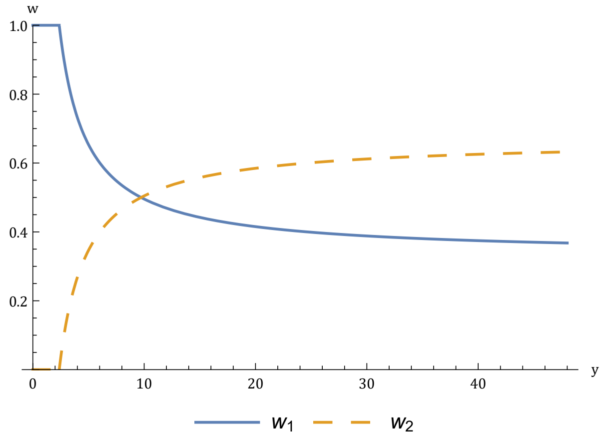


Figure 2.4: **Engel Curves**



Engel curves are nonlinear and the good associated to the lower need has a unitary income elasticity until a given point – with very low income, the individual spends all his income trying to satiate the lowest-order need. When the second need starts emerging as prepotent the budget share for the first begins to smoothly decrease in income. This is clear from fig. 2.3 but also from fig. 2.4. Therefore, contrasting with Lades (2013, p. 1039), we believe that boundary points as well as other implied nonlinearities, such as the depicted "kinks", can be very meaningful in demand analysis, both theoretically – understanding the income level for which only the lowest of needs is "prepotent" and higher needs are not "activated" – and empirically, as accounting for zero in demand surveys is sometimes troublesome due to the functional forms typically used in estimation.

Many other specifications of the "satiation function" are possible, and there might even be different functions for different orders of needs. As discussed above, it is also possible to nest this structure. We successfully developed a model where one need is given by a composition of two different needs pursuing the modeling strategy given in eq. 2.41, namely assuming

$$B(x_1, x_2, x_3) = \sigma_L(x_1, x_2) + \sigma_L(x_1, x_2)\sigma_3(x_3) \tag{2.3}$$

$$\sigma_L(x_1, x_2) = \sigma_1(x_1) + \sigma_1(x_1)\sigma_2(x_2) \tag{2.4}$$

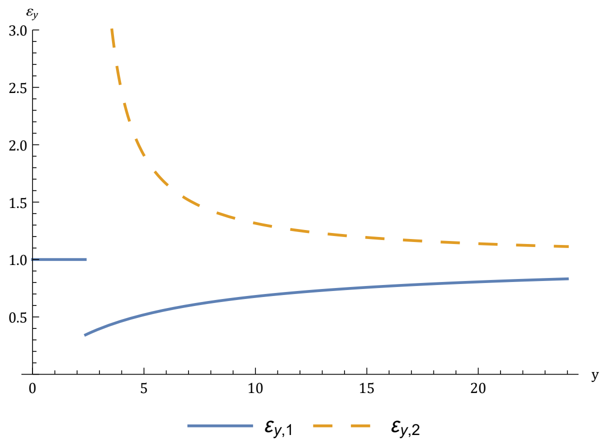
$$\sigma_i(x_i) = x_i\,, \qquad i = 1, 2, 3 \tag{2.5}$$

This additional example features a situation where the intermediate need/good goes from having an income elasticity higher than one to lower than one. From remark 2.9 we know that the income elasticities *are* ordered at the optimum. The outputs are not shown to avoid overburdening the text with graphical outputs and an infinity of variations could be exhibited. A graphical analysis is, however, presented in a digital appendix.

5.3. On Income Elasticities and Non-saturation

It is clear that given remark 2.10, with $\alpha_1 = \alpha_2$, it suffices that Maslow's condition is met to have ordered income elasticities, as $\sigma_1 \geq \sigma_2 \Rightarrow x_1 \geq x_2$. Thus, as can be explored in the cdf that graphically details the results (cf. digital appendices), this requires the price ratio p_1/p_2 not to be much larger than one.

Figure 2.5: **Income Elasticities**



As noted above, empirical studies indicate that the income elasticity for food is not only below one as it is decreasing in income. This contrasts with our results as in many cases, we can see all income elasticities converging to one (fig. 2.5), either from above or below. Though one would tend to associate full satiation and declining budget shares with decreasing income elasticities, the fact that income elasticities converge to one from below does not prevent the lower-order needs' budget shares to be driven down to zero. In fact, whether income elasticities converge to zero or slowly converge to one from below as income goes to infinity is barely indistinguishable in terms of their implications for satiation and budget shares: (i) in both situations it is possible to have complete saturation in the limit case; (ii) in both there might be all but one budget shares converging to zero; (iii) in both income elasticity at any stage before the limit is between zero and one.

In the short run it is possible that demand might tend close to full satiation in some cases. In this section needs are assumed to be *satiable* (bounded between 0 and 1) but no *saturation* occurs (Moneta and Chai, 2014, p. 896), i.e. quantities will still increase with higher income. If the categories of goods are broad enough, or well defined in terms of corresponding more or less directly to needs, normality of goods suffices for income elasticities to converge. Full satiation only occurs asymptotically, as in (Prais, 1952; Aitchison and Brown, 1954). Even if one has a limited want of quantities for a given class of goods, there may be an unlimited desire in improving quality (Marshall, 1920, III.II.1) and both are subject to an ordering of needs. Consequently, whilst it is possible to include status effects[8] (Keynes, 1930) to justify the persistent existence of increasing expenditure the model does not assume (nor reject) these are the forces driving normality.

In line with much of the philosophical, psychological and economic theory, we assume full satiability is not a feature of human nature, «because life itself is but motion, and can never be without desire, nor without fear, no more than without sense» (Hobbes, 1651) or, said in other terms, «man is a perpetually wanting animal» (Maslow, 1943, p. 395). The idea of unlimited needs in number is not necessary to nor contradictory of normality nor is that of satisfaction boundedness versus unboundedness of its cardinal value. It is difficult to put it in better terms that Menger (1871, ch. 3)

> From an economic standpoint, the qualitative differences between goods may be of two kinds. Human needs may be satisfied either in a *quantitatively* or in a *qualitatively* different manner by means of equal quantities of *qualitatively* different goods. With a given quantity of beech wood, for instance, the human need for warmth may be satisfied in a *quantitatively* more intensive manner than with the same quantity of fir. But two equal quantities of foodstuffs of equal food value may satisfy the need for food in qualitatively different fashions, since the consumption of one dish may, for example, provide enjoyment while the other may provide either no enjoyment or only an inferior one. With goods of the first category, the inferior quality can be fully compensated for by a larger quantity, but with goods of the second category this is not possible. (...) But even if unpalatable foods or beverages, dark and wet rooms,

8. The literature on status effects is abundant and diverse in concepts, using closely related/overlapping concepts such as status effects tout court (Frank, 1985; Hopkins and Kornienko, 2004; Becker et al., 2005), conspicuous consumption (Duesenberry, 1949; Ljundqvist and Uhlig, 2000), Veblen goods (Eaton and Matheson, 2013; Veblen, 1899), conformist, bandwagon and snobbish effects (Liebenstein, 1950; Corneo and Jeanne, 1997), envy and pride (Friedman and Ostrov, 2008), among others. The effects are obviously different according to the underlying motivation, as conspicuous consumption of expensive jewelry *to show* is not the same as buying and wearing expensive underwear as an identity symbol (O'Cass and McEwen, 2004, p. 27). The possibility of having status signaling functions arising "spontaneously" (Baudisch, 2007) further complicates the issue.

> the services of mediocre physicians, etc., are available in the largest quantities, they can never satisfy our needs as well, *qualitatively*, as the corresponding more highly qualified goods.

Illuminatingly, food *expenditure* never appears as decreasing with income – only budget shares do. People might even buy less food, but increase its quality (Manig and Moneta, 2014). With the xs denoting a quantity-quality index, whichever it may be, saturation might never occur, whilst satiation drives behavior. The idea of economic models subsuming a quantity-quality index is present in utilitarians (Bentham, 1781), marginalists (Edgeworth, 1881) and every now and then reappears explicitly in the models, though the behavior function's arrangement usually tries to fix the trade-off between quantities through the degree of substitutability, implying qualitatively different goods. It is nevertheless true that a more detailed model would distinguish between quantity and quality drawing e.g. from Nelson and Consoli's (2010) ideas, but that can perhaps be left to a lower level, within each need. Variety, novelty (Scitovsky, 1992; Witt, 2001; Chai, 2016) or the diffuse term quality are admitted to be actively operating in need satisfaction. If for particular goods satiation is (or should be) almost an unavoidable tenet, for categories that relate to needs it is arguable.

To conclude the discussion, we are here merely stating that people will always seek to be more satisfied in every need – to say otherwise would seem rather strange.

5.4. Frustration-Regression Mechanism

Other issues appear when one assesses how budget shares react to changes in prices. Increases in the price of good associated to the lowest-order need will increase the budget share of the same good. This gives modeling support to Maslow's tenet that people want to satisfy the most basic of needs when deprived in all but as prices rise this might hamper the ability of the individual to satisfy the need. Exogenous factors – here prices and income – condition the individual's ability to clear away from strong deprivation states in low-order needs (Maslow, 1943, p. 387; 1987, p. 55).

Figure 2.6: **Budget Shares and p_1**

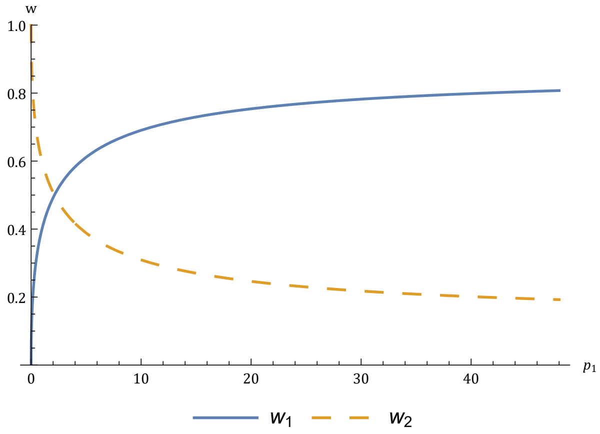


Figure 2.7: **Budget Shares and p_2 (I)**

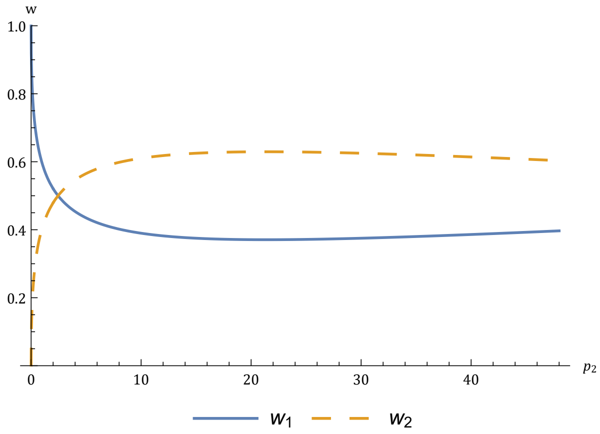
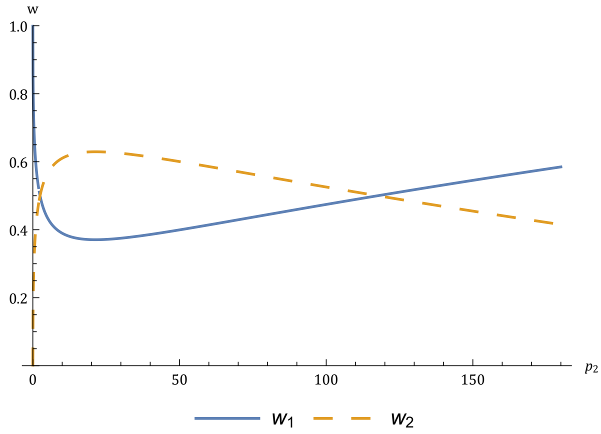


Figure 2.8: **Budget Shares and p_2 (II)**



Furthermore, the fact that income elasticity is positive implies that there are no Giffen goods. Nevertheless, given that expenditures are in most cases correctly observed whereas quantities are imperfectly so, budget shares that increase in a good's own price can account for "Giffen-like" behavior in expenditure even though quantities do decrease with price increases.

Analogously, the increase in price of the highest-order – here p_2 – will lead to increasing the budget shares of lower-order goods. This implied substitution across the different needs can be better understood recurring to Alderfer's (1969) Existence-Relatedness-Growth (ERG) theory. ERG enriches this Maslovian background perhaps with the possibility of *substituting* needs. The said «*frustration-regression* mechanism» (p. 151) entails that frustration in higher needs satisfaction leads the person to regress to lower ones, i.e. increase its lower-order level of satisfaction. Thus, the inability to satisfy higher needs due to price constraints, for instance, will lead the individual to compensate this deprivation by increasing satisfaction in lower-order needs. The examples assessed persistently show this feature, implying that this might be a general feature of the class of preferences defined in section 4.

6. Final Remarks

The class of ordered non-homothetic preferences presented in this paper constitute a first step towards enriching standard demand theory with insights from psychology in order to qualitatively explain the regularities persistently found in empirical analysis. Without relinquishing constrained optimization, indeed a useful device in modeling behavior, preferences for goods are assumed to be embedded within an ordered needs-based framework. This setting of preferences can be termed weakly lexicographic as it endogenously encodes an ordering in needs that gives rise to ordered and varying income elasticities and, consequently, nonlinear Engel curves. Albeit not ideal, due to strong nonlinearities which prevent closed-form solutions like those obtained with homothetic preferences, this preference structure nevertheless boasts an *explanatory* ability that is absent in other models.

The approach followed in this paper is related with the literature on learning to consume (Chai, 2016) as both plea for an enriched demand theory. However, the idea of operant conditioning (Skinner, 1938; Bandura, 1986; Staddon and Cerutti, 2003) that lies at the heart of the learning process is unable to account for needs for which no satiation has yet been experienced to any degree (Kenrick et al., 2010), and the theory of hierarchical prepotencies of needs is explicitly avoided in the learning to consume approach (Witt, 2001, p. 26). Moreover, the distinction between acquired and innate needs (Witt, 2001; Kaus, 2013; Chai, 2016) cannot disentangle why among both types satiation could be ordered, as suggested in some empirical research – usually alcohol and tobacco exhibit a parabolic (inverted U-shape) Engel curve (Banks et al., 1997; Moneta and Chai, 2014).

A relationship that is much discussed in the learning to consume literature is that between preferences and their impact on supply and on the structural features of the economy. In fact, not only is there a possible endogeneity of consumer preferences and economic growth (Becker, 1996, p. 19) but also the features of long-run growth have been increasingly related to preferences. As laid out by Pasinetti (1981), who explicitly models structural change by assuming a saturation point for all goods, and later discussed by Witt (2001) and Moneta and Chai (2014), among others, demand plays a crucial role in structuring industrial change and composition. Not wishing to downplay the importance of supply-side innovation and competition dynamics, we want to highlight that this is only one half of the story, as it is of the market. For instance, it is amply recognized that food being a necessity goes against the idea of balanced long-run growth (Browning, 2008, p. 851). The change in demand patterns brought about by phenomena such as differential satiation might be equally decisive in shaping production, as the examples in Chai (2016) illustrate. Innovation could in part be seen as aiming to boost income elasticity or, in other words, "escape satiation" (Chai and Moneta, 2014; Moneta and Chai, 2014).

More recently, the profession seems to be picking up interest on the topic of structural change in relation to growth using explicitly non-homothetic preferences to obtain non-unitary income elasticities (e.g. Foellmi and Zweimüller, 2006, 2008; Foellmi et al., 2014; Boppart, 2013; Boppart and Weiss, 2013; Comin et al., 2015). Although this renovated interest is attuned with the need to explicitly incorporate nonlinear Engel curves in macroeconomic models to account for unbalanced long-run growth, the explanatory content of such models seems limited. Moreover, while Boppart (2013); Boppart and Weiss (2013) derive a subclass of the aggregatable price-independent linear (non-homothetic) preferences developed in Muellbauer (1976) and Deaton and Muellbauer (1980a), most of the remaining models assume a representative agent's preferences without tending to the micro aggregation issue.

Finally, it should be noted that despite its generality, the approach followed in this paper assumes that goods used to satisfy a given need are not associated to other needs, which is not necessarily realistic. Nevertheless, this potential shortcoming (Maslow, 1943, p. 370) is, for both theoretical and empirical operational purposes, a common assumption (Engel 1857, p. 7; Chai and Moneta 2012, p. 653). Moreover, our framework does go beyond a one-to-one correspondence (Lades, 2013, p. 1031) as the argument in each satiation function (σ_i) can be in fact a vector of goods, i.e. $\mathbf{x}_i = (x_{i1}, x_{i2}, ..., x_{il_i})$, combined through some function providing the grounds for deriving a price aggregator.

A question for future research is whether consumer budgeting and mental accounting practices – for which there is empirical evidence (Heath and Soll, 1996) – is also informed by needs. Labeling and grouping expenditures differently can impact the budgeting practice and yield different results. As such, standard aggregations – e.g. the classification of individual consumption according to purpose (United Nations, 2000) – could be adjusted in the light of more substantive groupings. For instance, the use of factor analysis techniques to allocate goods into needs based on data on self-reported need satisfaction and consumption expenditures seems a particularly fertile one, combining insights from Barigozzi and Moneta (2016) and Tay and Diener (2011). This would help overcome confounding different groups with substitution of products that serve the same needs with rising income. A needs-based approach can lead to more "satisficing" and informed working assumptions (Chai and Moneta, 2012, pp. 653-4) as it provides a clearer rationale for a grouping of goods that is consistent with the existing standard classification.

The theoretical framework sketched above could also be extended to a setting with multiple consumers and firms. Additionally, there is the difficulty of considering infinite-period optimization, as intertemporal strict separability requires additivity of the intertemporally-extended behavior function (Streufert, 1999); otherwise, as Pollak and Wales (1995, p. 127) assert, separate budgeting is not possible, having a strong negative bearing on empirical identification strategies. A convenient but restrictive way to go around the problem, instead of relying on infinite-period optimization, is to see future consumption as a higher-order need and savings as the product of a myopic optimization.

As preferences are increasingly seen as the key to describe and explain economic phenomena such as structural change and unbalanced growth, there is a growing need for the economics profession to enlarge its "modeling portfolio". While it certainly constitutes one of the cornerstones of economics, demand theory is far from settled and the scope for further development is clear. Ordered preferences are an indispensable part of such development.

7. Appendices

7.1. Appendix 2.A. Digital Appendices

The digital appendices to this paper – two cdf and two pdf files – can be downloaded from the following links:

Digital Appendix Example 1 - CDF:
`https://sites.google.com/site/dgduartegoncalves/the-need-for-needs-digital-appendices/The%20Need%20for%20Needs.%20Example%201.cdf?attredirects=0&d=1`

Digital Appendix Example 1 - PDF
`https://sites.google.com/site/dgduartegoncalves/the-need-for-needs-digital-appendices/The%20Need%20for%20Needs.%20Example%201.%20Mathematica%20Code.pdf?attredirects=0&d=1`

Digital Appendix Example 2 - CDF
`https://sites.google.com/site/dgduartegoncalves/the-need-for-needs-digital-appendices/The%20Need%20for%20Needs.%20Example%202.cdf?attredirects=0&d=1`

Digital Appendix Example 2 - PDF
`https://sites.google.com/site/dgduartegoncalves/the-need-for-needs-digital-appendices/The%20Need%20for%20Needs.%20Example%202.%20Mathematica%20Code.pdf?attredirects=0&d=1`

where example 1 refers to the results obtained using the behavior function given by eq. 2.1 and example 2 to those using the behavior function defined in eq. 2.4.

A webpage was set up with an illustration:
`https://sites.google.com/site/dgduartegoncalves/preferences-behavior-and-needs-digital-appendix`

Besides the Wolfram Mathematica code and associated analytical results for the specific example under discussion, including the derivation of the demand functions, price and income effects (all in the pdf file), the digital appendix also includes a cdf file where dynamic graphs are exhibited, so as to relax the *ceteris paribus* assumption. In these graphs, the reader can change the values of prices and income in each graph and immediately perceive the changes.

7.2. Appendix 2.B. A Note on the Behavior Function and the Optimization Heuristic

Optimizing behavior appeared as a touchstone in economics in late eighteenth century, under the wing of Utilitarianism, with Bentham (1781, I.1, VI.1) claiming that pleasure and pain solely direct the actual human conduct. The progressive doing away with utility came with the succession of works by the marginalists (Jevons, 1871; Menger, 1871; Walras, 1874), then the ordinalists (Pareto 1906; Hicks and Allen, 1934a; 1934b) and finally the cornerstone laid out by Samuelson (1938). Samuelson developed what came to be known as the revealed preference or «choice-based» approach Mas-Colell et al. (1995, p. 5) to the consumer's behavior, which the same postulated having «freed from any vestigial traces of the utility concept» (p. 71). Through the introduction of the weak axiom of revealed preference (Samuelson, 1938, p. 65), the analysis was consequently laid down exclusively in terms of observable elements, being this all the more an important derivation because it did not get far astray from traditional preference theory in ordinal terms.

"Choice" is then understood as behavior, action, be it or not reflected and/or conscious – as opposed to decision, which is mostly treated as a reflected and conscious choice (Arrow, 1958, p. 1), and economics' concerns were re-centered in accounting for behavior and not (exclusively) decision-making, especially considering it is even less susceptible to empirical observation.

As another strand of results – an axiomatic definition of the conditions for preferences to have a real-valued continuous functional representation (Wold, 1943a,b, 1944)[9] , the strong axiom of revealed preference(Houthakker, 1950), the relation of integrability to Slutsky's (1915b; 1915a) matrix (Samuelson, 1950, p. 378) and ruling out of preference cycles (Ville and Newman, 1952; Hurwicz and Richter, 1979; Chipman, 2004) – asserted that consistent behavior was equivalent to consistent preferences in the form of some function when some smoothness requirements are imposed, the useful heuristics of optimization (Edgeworth e.g. 1881, pp. v, 12; Phlips 1983, p. 26) was then retained and reinterpreted in terms of choice instead of decision-making.

9. Though, as Debreu (1954) showed short-after, not all preference relations have such a functional representation. Cf. Mehta (1999) for a presentation of the conditions for existence and a succinct exposition of the theory of existence.

Our choice of using the designation of behavior function – finally dropping the term utility – is then merely a recognition that preference is nothing but the translation of «any motive which attracts us to a certain course of conduct» Jevons (1871, I.34), «consistent behaviour» (Little, 1949, p. 90) or «reasons for behavior» (Bowles, 2004, p. 99). This has been certainly underlying the extensions of the core drawn by Stigler and Becker's (1977) «New Consumer Theory» or much of the pleonastic behavioral economics.

As for the usual criticism of incurring in a tautology (see, e.g. Valente, 2012, p. 1044), Little counter-argues in perfection when he claims that

> If an individual's behaviour is consistent, then it must be possible to explain that behaviour without reference to anything other than behaviour. Someone, on the other hand, might object that market behaviour cannot be really explained by means of a map which is constructed out of nothing but that behaviour. The metaphor I have used to state this objection provides the answer. The terrain of England really is explained by a map of England. The map is constructed only by reference to this terrain (Little, 1949, pp. 97-8)

If the heuristic of optimization is equivalent to consistent behavior (and moreover, any behavioral rule can be translated into an optimization problem – cf. Rabin 2013, p. 529, Stahl 2013) and this heuristic is furthermore more prone to rich analytical techniques (Stigler and Becker, 1977, pp. 76-7), then we see no logical reason not to use this approach. Impressively, the standard objective function optimizing account of behavior has also been successful in biology, when trying to account for *non-human* behavior using standard demand theory – e.g. Kagel et al. (1980); Kagel et al. (1981). In these studies, For instance, Kagel et al. (1980, p. 263) claim that – an I will quote at length

> What it may suggest is that evolutionary pressures have been such that humans, along with other animals, have behavioral repertoires that can be characterized as solutions to a constrained optimization problem. Such inherited behavioral repertoires are of obvious value in the evolutionary struggle for survival. Furthermore, whether or not animals (or humans for that matter) have consciously thought out their behavior is irrelevant to our characterization of that behavior as a solution to a constrained optimization problem. Economic theorists have long recognized this. As Samuelson (1947) notes, "it is possible to formulate our conditions of equilibrium as those of an extremum problem, even though it is admittedly not a case of an individual's

> behaving in a maximizing manner, just as it is often possible in classical dynamics to express the path of a particle as one which maximizes (minimizes) some quantity despite the fact that the particle is obviously not acting consciously or purposively [p. 23]." The pragmatic value of writing theories as solutions to constrained optimization problems is well known and is, of course, not affected by our results.

A final take on the usefulness of the optimizing heuristic is given by Rabin (2013), who recalls not only that the distinction between "bounded-rationality" and optimizing behavior is not at all clear-cut, but also that «[t]he emphasis is on developing models improving behavioral realism that can be used as inputs into economic theory by dint of their precision and broad applicability. Striving for realism-improving theories to be maximally useful to core economic research suggests a particular approach: portable extensions of existing models» (p. 531).

7.3. Appendix 2.C. Additional Remarks on the Behavior Function

The general behavior framework can also be parameterized, through the σ-functions and/or by premultiplying each term of the summation in eq. 2.7 by a specific parameter, i.e.

$$B(\mathbf{x}) = \beta_1\sigma_1(x_1) + \beta_2\sigma_1(x_1)\sigma_2(x_2) + ... + \beta_l\sigma_1(x_1)\sigma_2(x_2)\cdots\sigma_{l-1}(x_{l-1})\sigma_l(x_l) \tag{2.1}$$

$$= \sum_{j=1}^{l}\prod_{h=1}^{j}\beta_h\sigma_h(x_h) \tag{2.2}$$

Notwithstanding, if the purpose of the "flexible" demand systems is to be general enough to best describe the relations given by the data, e.g. QUAIDS, here the purpose is *not* to describe but to explain. That is, though parameterization could improve this model's ability to fit data, it would probably do a worse job than many already existing applied demand systems.

Still regarding eq. 2.2, if all parameters are zero except the one in the last term of the summation, that is, if $\beta_1 = \beta_2 = \cdots = \beta_{l-1} = 0$ and $\beta_l > 0$, we back to a Cobb-Douglas function. With additional parameterization other models could be obtained as particular cases, but this deviates attention from where it should be focused: the non-homothetic ordering.

That existing models are unable to explain – or even reproduce – the empirical regularities discussed above is not in itself a reason to abandon the optimizing assumption as Lades (2013, p. 1028) hints. Decision algorithms actually do not differ from optimizing behavior, given the appropriate functions. Moreover, the fact that standard demand theory admits but does not entail the empirical regularities discussed above is no reason to abandon it, as Chai and Moneta (2012, p. 655) seem to imply: a theory's incompleteness does not imply it is wrong. Consequently, we aimed at following Rabin's (2013, p. 531) maxim of «[s]triving for realism-improving theories to be maximally useful to core economic research» by developing portable extensions of existing models.

7.4. Appendix 2.D. Proofs of Propositions 2.7 and 2.8

Proof of proposition 2.7

Proof. From the interior equilibrium condition (eq. 2.21)

$$\frac{d\sigma_1}{dx_1}\frac{1}{\sigma_1}\frac{b_1}{b_2}\frac{p_2}{p_1} = \frac{d\sigma_2}{dx_2}\frac{1}{\sigma_2} \Leftrightarrow \tag{2.3}$$

$$\Leftrightarrow \frac{d\sigma_1/dx_1}{\sigma_1}\frac{\sigma_2}{d\sigma_2/dx_2} = \frac{b_2}{b_1}\frac{p_1}{p_2} \Leftrightarrow \tag{2.4}$$

$$\Leftrightarrow \frac{d\sigma_1/dx_1}{\sigma_1} = \frac{d\sigma_2/dx_2}{\sigma_2}\frac{b_2}{b_1}\frac{p_1}{p_2} \tag{2.5}$$

Additionally, one has

$$\frac{d b_2/b_1}{dx_2} = \frac{b_2}{b_1}\frac{1}{\sigma_2}\frac{d\sigma_2}{dx_2} - \frac{b_2}{b_1}\frac{b_2}{b_1}\frac{1}{\sigma_2}\frac{d\sigma_2}{dx_2} = \left(1 - \frac{b_2}{b_1}\right)\frac{b_2}{b_1}\frac{d\sigma_2}{dx_2}\frac{1}{\sigma_2} \tag{2.6}$$

$$\frac{d\frac{d\sigma_1/dx_1}{\sigma_1}}{dx_1} = \left(\frac{d^2\sigma_1}{(dx_1)^2}\frac{1}{d\sigma_1/dx_1} - \frac{d\sigma_1}{dx_1}\frac{1}{\sigma_1}\right)\frac{d\sigma_1}{dx_1}\frac{1}{\sigma_1} \tag{2.7}$$

To ease the notation, let us define

$$\varepsilon_{\sigma_i} = \frac{d\sigma_i}{dx_i}\frac{x_i}{\sigma_i} \quad > 0 \quad \text{(by definition: cf. section 4.1)} \tag{2.8}$$

$$\varepsilon^{(2)}_{\sigma_i} = \frac{d^2\sigma_i}{(dx_i)^2}\frac{x_i}{d\sigma_i/dx_i} \tag{2.9}$$

Then,

$$\frac{d\frac{d\sigma_1/dx_1}{\sigma_1}}{dx_1} = \left(\varepsilon^{(2)}_{\sigma_1} - \varepsilon_{\sigma_1}\right)\frac{d\sigma_1}{dx_1}\frac{1}{\sigma_1}\frac{1}{x_1} \tag{2.10}$$

$$\frac{d b_2/b_1}{dx_2} = \left(1 - \frac{b_2}{b_1}\right)\varepsilon_{\sigma_2}\frac{b_2}{b_1}\frac{d\sigma_2}{dx_2}\frac{1}{\sigma_2}\frac{1}{x_2} \tag{2.11}$$

Differentiating both sides of eq. 2.5 wrt. x_1, one obtains

$$\frac{d\frac{d\sigma_1/dx_1}{\sigma_1}}{dx_1} = \left(\frac{d\frac{d\sigma_2/dx_2}{\sigma_2}}{dx_2}\frac{b_2}{b_1}\frac{p_1}{p_2} + \frac{d\sigma_2}{dx_2}\frac{d b_2/b_1}{dx_2}\frac{p_1}{p_2}\right)\frac{dx_2}{dx_1} \Leftrightarrow \tag{2.12}$$

$$\Leftrightarrow \left(\varepsilon^{(2)}_{\sigma_1} - \varepsilon_{\sigma_1}\right)\frac{d\sigma_1}{dx_1}\frac{1}{\sigma_1}\frac{1}{x_1} = \left(\varepsilon^{(2)}_{\sigma_2} - \varepsilon_{\sigma_2} + \left(1 - \frac{b_2}{b_1}\right)\varepsilon_{\sigma_2}\right)\frac{d\sigma_2}{dx_2}\frac{1}{\sigma_2}\frac{1}{x_2}\frac{b_2}{b_1}\frac{p_1}{p_2}\frac{dx_2}{dx_1} \tag{2.13}$$

Replacing the result from eq. 2.4, one has then

$$\left(\varepsilon^{(2)}_{\sigma_1} - \varepsilon_{\sigma_1}\right)\frac{1}{x_1} = \left(\varepsilon^{(2)}_{\sigma_2} - \varepsilon_{\sigma_2} + \left(1-\frac{b_2}{b_1}\right)\varepsilon_{\sigma_2}\right)\frac{1}{x_2}\frac{dx_2}{dx_1} \Leftrightarrow \tag{2.14}$$

$$\Leftrightarrow \frac{dx_2}{dx_1} = \frac{\varepsilon^{(2)}_{\sigma_1} - \varepsilon_{\sigma_1}}{\varepsilon^{(2)}_{\sigma_2} - \varepsilon_{\sigma_2} + \left(1-\frac{b_2}{b_1}\right)\varepsilon_{\sigma_2}}\frac{x_2}{x_1} \tag{2.15}$$

$$= \frac{\varepsilon_{\sigma_1} - \varepsilon^{(2)}_{\sigma_1}}{\varepsilon_{\sigma_2} - \varepsilon^{(2)}_{\sigma_2} - \left(1-\frac{b_2}{b_1}\right)\varepsilon_{\sigma_2}}\frac{x_2}{x_1} \tag{2.16}$$

From the Ordered Income Elasticities Condition (eq. 2.33),

$$\frac{\partial x_1}{\partial y}\frac{y}{x_1} = \varepsilon_{y,1} < \varepsilon_{y,2} \Leftrightarrow \tag{2.17}$$

$$\frac{dx_2}{dx_1} \geq \frac{x_2}{x_1} \tag{2.18}$$

Then, if $\varepsilon_{y,1} < \varepsilon_{y,2}$, it must be the case that

$$\varepsilon_{\sigma_1} - \varepsilon^{(2)}_{\sigma_1} \geq \varepsilon_{\sigma_2} - \varepsilon^{(2)}_{\sigma_2} - \left(1-\frac{b_2}{b_1}\right)\varepsilon_{\sigma_2} \tag{2.19}$$

This concludes the proof of proposition 2.7. □

Proof of proposition 2.8

Proof. As, by definition, $b_1 \geq b_2$, then $1 \geq \frac{b_2}{b_1}$. Consequently,

$$\left(\varepsilon_{\sigma_1} - \varepsilon^{(2)}_{\sigma_1} \geq \varepsilon_{\sigma_2} - \varepsilon^{(2)}_{\sigma_2}\right) \Rightarrow \left(\varepsilon_{\sigma_1} - \varepsilon^{(2)}_{\sigma_1} \geq \varepsilon_{\sigma_2} - \varepsilon^{(2)}_{\sigma_2} - \left(1-\frac{b_2}{b_1}\right)\varepsilon_{\sigma_2}\right) \tag{2.20}$$

$$\Rightarrow \quad \varepsilon_{y,2} > \varepsilon_{y,1} \qquad \text{(from proposition 2.7)} \tag{2.21}$$

This concludes the proof of proposition 2.8. □

III

Melioration and Needs

Melioration and Needs

Abstract

When discussing empirical evidence on income elasticities it is not uncommon to see satiation and needs as possible reasons underlying the differences in Engel curves. Moreover, data seems to support the existence of path dependence in demand. This paper proposes an explanatory model alternative to the common assumption of habit formation by combining the psychological tenets of hierarchical needs and melioration, letting preferences dynamically adjust according to differential satiation. The resulting structure – easily coupled with other specifications – is able to qualitatively reproduce nonlinear Engel curves while providing a straightforward explanation of their shape.

Keywords: preferences; hierarchical needs; income elasticity; Engel curves.

JEL classification: D01; D03; D11; D91.

1. Introduction

Non-Varian hoc; ergo ad hoc

(Rabin, 2002, p. 676)

Needs and satiation are terms that hardly appear in graduate microeconomics textbooks – except possibly as "we will need this lemma to prove the following theorem" or "assume preferences are locally nonsatiable". Melioration for sure does not appear at all. As Rabin (2002, p. 676) explains, there is a common bias in the profession given by the ditto in epigraph that «[t]ranslated from the Latin, this means: "That assumption was not in our graduate microeconomics text; therefore it is some random assumption that you're making up"».

One can counter this bias with a simple "theorem". **Theorem:** *Assume homothetic path-independent preferences. Then we are assuming linear Engel curves, which is neither realistic nor does it fit the data properly.* Engel curves have been shown to be nonlinear, at least for some goods (Banks et al., 1997; Moneta and Chai, 2014). And while we are able to describe these using extensive parameterization, we still fail to understand why they are so. That is, the general consumer constrained-optimization framework does not provide an explanation and existing models impose too stringent conditions and lose this stylized fact from sight.

Additionally, there is increasing evidence that demand is path-dependent – that is, the past "isn't even past" as Faulkner (1951) put it. Most economists tackle this issue using the assumption of habits, which in simple terms translates to saying that "the more you consumed in the past, the more you will consume in the present". While this is a fairly reasonable assumption, it cannot explain why people want more of things which they have not consumed at all. Moreover, it does not explain why, for instance, expenditures in clothing show a lower path dependence than those in food (Browning and Collado, 2007).

The keyword, which has already been used four times in this introduction, is *explain*. Without a proper understanding of the causal mechanisms underlying demand, an empirical demand model might provide good insights by fitting the data and making predictions, but cannot explain the causes. The model this paper puts forth suggests a different way to look at the patterns in the data; theory, etymologically, means *to see*.

In particular, this paper combines the Maslovian (1943) thesis that needs are hierarchical with that of demand being path-dependent. The former implies that when all needs are at an equal state of deprivation, a person will have more reasons to satiate lower needs than higher ones (what good is a smartphone if we have no money left to eat at all?). But given changes in the external environment, say if one gets a raise, it takes some time for individuals to adjust their demand patterns. If one earns ten times more, there are grounds to think one will not spend ten times more to satisfy lower needs, but instead will devote a larger share of income to higher ones. How much to spend in these higher needs will take some time to figure out, as the learning to consume literature posits (Witt, 2001; Chai, 2016). This learning process was elsewhere called *melioration* (cf. e.g. Herrnstein et al., 1993) and shows some similarities to "myopic habits" (Pollak, 1970; von Weizsäcker, 1971), though illuminating it in a very different manner.

This paper shows that combining these elements can provide an explanation for having both nonlinear Engel curves and short-run path dependence in demand, resulting in a situation where individuals faced with an increase (or decrease) in income will tend to increase the share they spend on satisfying higher (lower) needs, while going through an adjustment period. In sum, we show how ordered need satiation can be embedded in a dynamic setting.

The remaining sections of this paper will proceed as follows: the next section (2) reviews the literature on Engel curves and argues for ordered needs as a possible underlying cause; section 3 contrasts habits and melioration; section 4 sets up the model and presents some analytical results while section 5 discusses the model in light of a revealing example; lastly, section 6 concludes with some final remarks. The appendices (section 7) to this paper contain complementary digital appendices (7.1), additional outputs (7.2) and an example of how to nest this model in other preference structures (7.3).

2. Engel Curves, Satiation and Ordered Needs

A horse, a horse! My kingdom for a horse!

(Shakespeare, *King Richard III*, 5.4)

There is ample evidence that income elasticities are not unitary, i.e., some goods' budget shares rise with income while others decrease. The most typical example is asserting that the demand for food has an income elasticity that is positive but lower than one, an assertion known as "Engel's law" (Engel, 1857, 1895). Though not well supported by Engel himself (Stigler, 1954, pp. 98 ff.), it has proved to be a strikingly robust empirical finding (Browning, 2008)[1], verified in whichever setting analyzed: cross-section, time series or panel data; and at any aggregation level, be it household, national or cross-country. The curve describing the – *ceteris paribus* – functional relationship between demand and income is therefore known as the Engel curve (Lewbel, 2008), which can be defined for some good or expenditure category i as $w_i(y)$, where w_i denotes the budget share associated to the good in question and y income.

Besides the fact that budget shares do vary with income, there is also some evidence that Engel curves are nonlinear, implying that income elasticity also varies with income (Banks et al., 1997). When considering this empirical regularity, it is not uncommon

1. The fact was corroborated by several authors, namely – and without any pretension of being exhaustive – Houthakker (1957); Blundell et al. (1993); Banks et al. (1997); Seale and Regmi (2006); Chakrabarty and Hildenbrand (2011); Kaus (2013); Chai and Moneta (2014); Moneta and Chai (2014).

to find suggestions that the phenomenon of changing "propensity to consume" might be due to the degree of satiation (Prais 1952; Aitchison and Brown 1954; Houthakker 1961, pp. 726-7; Blundell et al. 1993, p. 582; Moneta and Chai 2014). This begs the question: satiation of what?

Drawing from an old tradition within economic theory (Menger 1871, p. 48; Engel 1895), some economists (Moneta and Chai, 2014; Barigozzi and Moneta, 2016; Chai, 2016) posit that needs are assumed to underlie the structure of preferences. Moreover, needs are assumed to be hierarchical or ordered. This tenet has some grounding in behavioral psychology theories that explicitly link behavior and needs such as "Maslovian" hierarchical needs theories.

Maslow's (1943; 1987) account of hierarchical needs is of special relevance, not because of the specific needs list he proposed – others have been suggested (e.g. Alderfer, 1969; Galtung, 1980; Deci and Ryan, 2000; Bernard et al., 2005; Kenrick et al., 2010) and, in the end, Maslow (1943, pp. 370-1) argued against trying to pinpoint *the* list – but due to the propositions it put forth.

Firstly, «needs are neither necessarily conscious nor unconscious» (Maslow, 1943, p. 370), making them suitable as a starting point of a choice – as opposed to decision (Arrow, 1958, p. 1) – theory. Needs decisively influence the individual's preferences, her "reasons for behavior" (Bowles, 2004, p. 99), while behavior itself is nevertheless subject to external constraints (Maslow, 1943, p. 387; 1987, p. 55), taking us close to a Samuelsonian-Littleian tradition (Samuelson, 1938; Little, 1949).

Secondly, each need is never fully satiated, given that «man is a perpetually wanting animal» (Maslow, 1943, p. 395), which implies that if one considers the demand for *bundles* of goods associated to some need, it is never truly saturated as needs never reach complete satiation. In other words, as «needs may be satisfied either in a *quantitatively* or in a *qualitatively* different manner by means of equal quantities of *qualitatively* different goods» (Menger, 1871, ch. 3), and the desire for higher quality goods can then be unlimited (Marshall, 1920, III.II.1). Quality is admitted to be actively operating in need satisfaction, whether quality is translated into variety, novelty (Scitovsky, 1992; Witt, 2001; Chai, 2016) or some combination of particular traits (Valente, 2012).

Finally, needs will tend to be ordered in terms of "prepotency", given by each need's closeness to basic needs (Maslow, 1943, pp. 370, 388-9). When individuals are unable to satisfy their most basic needs, e.g. when $y \to 0$, these needs fully determine the individual's behavior, i.e. they are fully prepotent. As lower needs are increasingly satisfied, higher needs are activated, their prepotency rises and eventually their importance in influencing individual behavior surpasses lower needs'. Put differently, at very low income levels individuals sacrifice expenditure on higher needs – an idea at the core of Engel's work (Chai and Moneta, 2012, pp. 654-5) – but as purchasing power increases, the satiation of lower needs «permits the higher want to manifest itself» (Jevons, 1871, ch. III, p. 54). This smooth ordering is different from a lexicographic one. Notwithstanding, when everything is failing, lower needs come first. As Shakespeare suggested: what good is a kingdom when one's life is at risk?

The set of needs has been assumed to be universal by every needs-based theory and indeed there is support for this stance in the psychology literature (Tay and Diener, 2011). Beyond that, we are particular interested in how a common structure of needs can be modeled, allowing different behaviors to emerge (Alderfer, 1977, p. 661). Paraphrasing Stigler and Becker (1977), no relevant behavior has been better understood by simply positing a difference in the structure of preferences .

In order to explain this underlying relationship between demand and satiation leading to varying income elasticities one must go further than the traditional models, as these[2] either rely on fixed homothetic preferences – e.g. the constant elasticity of substitution function and its particular cases –, which necessarily leads to demand for each good having unit income elasticity (Chipman, 1974) or "flexible" models, such as Translog (Jorgenson and Lau, 1975), (QU)AIDS (Deaton and Muellbauer, 1980a; Banks et al., 1997) and variants. Though capable of approximating any theoretically consistent demand system and its income, own-price and cross-price derivatives and elasticities (Pollak and Wales, 1995, p. 60) and, in some of its versions, such as QUAIDS, able to produce nonlinear (quadratic) Engel curves, the latter class of models arguably achieves maximal data-fitting

2. We are purposely leaving out purely empirical models, those not consistent with standard demand theory nor supported by any alternative theory, such as the Working-Leser model (Working, 1943; Leser, 1963) and the sigmoid-shaped demand function proposed by Prais (1952).

at the cost of minimal explanatory power, thus casting little light on the reality they describe.

Other existing alternatives are also deemed inadequate. For instance, lexicographic models (Fishburn, 1974; Drakopoulos, 1994; Martínez-Legaz, 1999), sometimes associated with need satisfaction, are too restrictive in their setting, as they constrain simple substitution, impose severe computational requirements and are incompatible with most of the standard analytical methods, while they also fail to add any substantive content in order to explain why demand behaves as it does (Chai and Moneta, 2012, p. 656). Finally, Lades (2013) recently developed a matching model to account for differential satiation. Rejecting optimization as a baseline heuristic, matching models are based upon the idea that individuals match incentives and costs at the mean instead of at the margin (Herrnstein and Vaughan Jr., 1980; Herrnstein, 1990; Herrnstein and Prelec, 1991). However, it is also known that any behavior given by a rule or algorithm can be translated into an optimization problem (Rabin 2013, p. 529, Stahl 2013) and, in the case of Lades's (2013) the resulting demand function is indistinguishable from one obtained through the constrained optimization of a Cobb-Douglas function describing preferences depending on income – a simplified version of a Fechner-Thurstone model (Basmann et al., 2009). Having preferences depend on income (or prices) is, similarly to the lexicographic case, not instructive of why varying income impacts preferences for some goods more than others.

In sum, existing alternatives to model demand behavior are unable to satisfactorily link preferences, satiation and demand. In the following section we will present a demand model with needs-based endogenous preferences aimed at explaining nonlinear Engel curves through a «rich behavioral foundation» (Chai and Moneta, 2010, p. 226).

3. Endogenous Preferences and Melioration

the man is not the same at the beginning as at the end

(Marshall, 1920, Bk. III, Ch. III, p. 61)

In their insightful paper «De Gustibus non Disputandum est», Stigler and Becker (1977) argue against the traditional resistance within economics (Friedman 1962, p. 13; Houthakker 1961, p. 733) towards modeling preferences as depending on a person's history and situation. There are several factors influencing preferences (Bowles, 1998), such as other people's preferences and one's past choices. Among the latter consumption habits are more commonly employed in economic models. While these have been used as a stand-alone tenet contributing to account for aggregate consumption's "excessive smoothness" (Campbell and Deaton, 1989; Carroll et al., 2000; Fuhrer, 2000), for individual-level habits (Pollak, 1970, 1976; Becker, 1992, pp. 328, 330) and for addiction (Stigler and Becker, 1977; Becker and Murphy, 1988), empirical research has also provided arguments against path independence (see e.g. Browning, 1991).

Habitual behavior defines a situation drawing «a positive relation between past and current consumption» (Becker, 1992, p. 328). Existing habit models come in two different versions: one based on successive instantaneous optimization – also said to be "myopic" or "naive" – (Pollak, 1970; Pollak and Wales, 1995; von Weizsäcker, 1971; Phlips, 1983) and another relying on intertemporal optimization approach – the so-called "rational" version – (Stigler and Becker, 1977; Becker, 1992, 1996)[3]. The difference between them is that in the former, consumer behavior does not take into account the effects of current actions on future preferences, while in the latter it does. Habits are brought about usually by making the parameters in a linear expenditure system or Stone-Geary function linearly dependent on past consumption (Pollak, 1970) or on some stock variable related to it (Phlips, 1983, ch. 7). Becker's (1996) approach for endogenizing preferences involves a pass-through mechanism where choices are translated into a "stock" subject to depreciation (as habits with forgetfulness) and then applies intertemporal optimization. The path dependence is thus captured by the idea of personal stock, while behavior is fully forward looking (pp. 6-7). This Beckerian approach, on the other hand, «is incompatible with intertemporal separability», as Pollak and Wales (1995, p. 127) rightfully point out, and the data seems to support instantaneous habit formation rather than the intertemporal view (Muellbauer, 1988; Loewenstein et al., 2003).

While the inclusion of path-dependent preferences, even in "flexible" functional forms, changes income-elasticity estimates significantly (Manser, 1976; Browning and Collado, 2007) and can certainly account for an important part of the story, habitual behavior is unable to link demand to satiation, since habits define a positive relation of present to past

3. Another distinction regards the modeling strategy, where subtractive (Pollak, 1970) and multiplicative (Abel, 1990; Galí, 1994) habits are the most common, following Carroll's (2000) terminology. A comparison of both approaches in an intertemporal optimizing framework can be found in Bossi and Gomis-Porqueras (2009).

consumption. Moreover, this formulation can be linked to an operant conditioning behavior (Skinner, 1938; Bandura, 1986; Staddon and Cerutti, 2003) as argued by Scitovsky (1992, p. 126) and thus cannot account for why individuals can feel deprived in needs they never have satisfied to any degree. Consequently, while the notion of a consumption adjustment due to path dependence is appealing, if needs are to play a relevant part one must turn away from habits and seek a proper understanding of this adjustment process elsewhere. In our view, two concepts are crucial: internalities and melioration.

There is an *internality* (Loewenstein et al., 2003, p. 1222) whenever the individual's current behavior impacts future preferences (or "reasons for behavior") yet the individual does not incorporate this into his or her actions. Stepping away from discussions of suboptimality as these have little bearing on behavior description – changing preferences are «a fact (...), not an indication of irrationality» (Rabin, 2013, p. 538) –, the notion of internalities highlights an important feature of a given behavior which goes beyond the case of an unforeseen addiction. For instance, ordering too much food at the restaurant when one is too hungry is a good example where the concept of internality is applicable, but not that of habit. In this case, the individual underestimates how satiated he or she will be. Internalities are thus a form of projection bias (Rabin, 2013, p. 538), i.e. a setting where, because of current preferences or focus, people (actively or passively) mispredict their preferences in future situations.

On the other hand *melioration*, in our own portable and flexible interpretation of the concept[4] refers to the behavior adjustment *process* (Loewenstein et al., 2003) that arises due to the existence of internalities. Returning to our example, a person might recall having ordered too much food when in a similar state of hungriness and yet, the next time, may still get a larger than ideal order; on the contrary, she may restrict her order too much this time, ending up hungry. Melioration can be seen as the process where one searches for the right amount, a learning process.

As Herrnstein et al. (1993, p. 150) state, «[m]elioration is readily linked with everyday experience. People often seem disposed to ignore the impact of current consumption on future tastes». In their example on the same page, the difference Herrnstein et al.

4. We thus aim to disentangle melioration from matching. Although these were originally coupled together, we believe that the concept's significance extends beyond its original context (Herrnstein and Vaughan Jr., 1980).

(1993) make between a “meliorator” and a “maximizing consumer” is merely that the “meliorator” is subject to a full projection bias, while the behavior process that describes the “maximizing consumer” is the intertemporal optimization of the behavior function taking into account how preferences are changed. In other words, melioration provides substance for what in the habits-related strand of the literature on endogenous preferences is called “myopic” or potentially (Strotz, 1955) “time-inconsistent” behavior. Finally, it is important to note that melioration can lead to non-monotonic dynamic processes, as in the example presented in Herrnstein and Prelec (1991, pp. 138-40). If a melioration process reaches an asymptotically stable steady state, it reaches an exact optimization solution, though it is possible that meliorating outcomes are unstable (Herrnstein and Prelec, 1991, pp. 147-8). Thus, similarly to the instantaneous version of habit formation, short-run and long-run demand functions differ (Pollak, 1970, 1976).

4. Combining Melioration and Needs

“reality” (...) becomes intelligible only to the extent that it is interpreted

(Phlips, 1983, p. 26)

If economics currently possesses models able to approximate demand functions well enough, it lacks a fully-fledged model able to explain the evidence brought forth by empirical research. In this section we will present a model combining need satisfaction with path-dependent demand, beginning with the relevant definitions, then showing that the melioration process has an equilibrium and that, with some conditions on the demand function, this equilibrium is stable. Lastly, we will discuss steady-state price and income effects.

4.1. Definitions

Any function describing preferences «can be made dynamic by allowing some or all of its parameters to depend on past consumption» (Pollak, 1970, p. 760). This parameter will be assumed to translate the associated needs’s propotency, i.e. its importance. In particular, let $\psi_{i,t}$ denote the prepotency of need i for a given individual at time t and $\sigma_{i,t}$ the degree of satiation of the same need. A higher prepotency, using the Maslovian term, implies a greater urgency in satisfying the associated need.

Following the Jevonian and Maslovian insights discussed above, we have that the higher the satiation of a given need, the lower its prepotency. Let us define satiation, $\sigma_{i,1}$, as depending on a given good or bundle (we will call it good for convenience), $x_{i,t}$, where

$$\sigma_{i,t} = \sigma_i(x_{i,t}) \qquad \sigma_i : \mathbb{R}_+ \to \mathbb{R}_+ \qquad \frac{d\sigma_i}{dx_i} > 0 \qquad \frac{d^2\sigma_i}{(dx_i)^2} \leq 0 \tag{3.1}$$

The set of needs is assumed to be limited in number, e.g. $\boldsymbol{\sigma} \in \mathbb{R}^l_+$, there being l needs, prepotencies and goods.

A simplifying assumption will be that of separability, where each given good satisfies at most one need. Though in reality this assumption might be too stringent, it is a common operational assumption, both theoretical an empirical. Moreover, that each good satisfies at most one need does not imply the converse, that is, *we will not* assume that each need will be satisfied by at most one good – an example is given in appendix 3.C.

Throughout, it will be assumed that the individual behavior reacts to past deprivation, i.e. that prepotency is a function of the degree of satisfaction of the same need in the previous period, though the time-span does not the matter: it might be a month, a year or a day. Naturally, the higher the degree of satiation of a given need, the lower the prepotency associated to the same, i.e.

$$\frac{\partial \psi_{i,t}}{\partial \sigma_{i,t-1}} < 0 \tag{3.2}$$

It can be now seen that prepotencies depend negatively on one period-lagged consumption, what follows directly from the definitions above: if ${d\sigma_{i,t}}/{dx_{i,t}} > 0$ and ${\partial \psi_{i,t}}/{\partial \sigma_{i,t-1}} < 0$, then ${\partial \psi_{i,t}}/{\partial x_{i,t-1}} < 0$.

If one interprets prepotencies as the relative importance an individual attributes to a given need, consciously or not, one can define

$$\sum_{i=1}^{l} \psi_{i,t} = 1 \tag{3.3}$$

Thus, $\psi_{i,t}$s are easily interpreted as a share of the attention a given individual attributes to each need, with each $\psi_{i,t} \in [0, 1]$. If one is higher, the sum of the others would be lower. As prepotencies are assumed to add up to one, we leave the prepotency associated to the highest-order need, $\psi_{l,t}$ to be given by the "residual attention", i.e. $\psi_{l,t} = 1 - \sum_{i=1}^{l-1} \psi_{i,t}$.

Additionally, define $\kappa_{i,t}$ as

$$\kappa_{i,t} = \begin{cases} 1 - \sum_{h=1}^{i-1} \psi_{h,t}\,, \quad i = 2, 3, ..., l \\ 1\,,\ i = 1 \end{cases} \tag{3.4}$$

Hence, $\kappa_{i,t}$ denotes how much importance a given individual attributes to needs i and higher. It follows that $\psi_{l,t} = \kappa_{l,t}$.

Let for now us define $\varphi_{i,t}$ as the prepotency of need i in the situation where all the lower needs are fully satisfied. Formally, this means

$$\kappa_i = 1 \Rightarrow \quad \psi_{i,t} = \varphi_{i,t}\,, \quad i = 1, 2, 3, ..., l-1 \tag{3.5}$$

In this situation the prepotency of need i would only depend on its degree of satiation, as lower needs impose no constraint. And thus, the $\varphi_{i,t}$ has the same definitions as above.

$$\varphi_{i,t} = \varphi_i(x_{i,t-1}) \in [0, 1] \tag{3.6}$$

$$\frac{d\varphi_{i,t}}{dx_{i,t-1}} = \frac{d\varphi_{i,t}}{d\sigma_i}\frac{d\sigma_i}{dx_{i,t-1}} < 0 \qquad i = 1, 2, 3, ..., l-1 \tag{3.7}$$

As mentioned above, there is cause to assume needs are never fully satiated. And as full deprivation would the absolute prepotency of the need in question, one has

$$\varphi_i(x_{i,t-1})\Big|_{x_{i,t-1}=0} = 1 \tag{3.8}$$

$$\varphi_i(x_{i,t-1}) \in (0, 1] \tag{3.9}$$

$$x_{i,t-1} \to +\infty \Rightarrow \varphi_i(x_{i,t-1}) \to 1 \qquad i = 1, 2, 3, ..., l-1 \tag{3.10}$$

However, as Maslow (1943, p. 370) asserts, the prepotency of a given need depends negatively on those associated with lower needs. The more stringent are needs lower than i, the lower is $\kappa_{i,t}$ and, therefore, the lower is $\psi_{i,t}$ too. Nevertheless, the converse is not true: higher needs deprivation does not impact lower needs' prepotencies. This can be formally stated as

$$\psi_{i,t} = \kappa_{i,t}\varphi_{i,t}\,, \quad i = 1, 2, ..., l-1 \tag{3.11}$$

It is reasonable to believe that past prepotencies still have a bearing on current ones. Individuals might be able to recognize past realizations but their focus cannot adjust perfectly. If one attributes a high importance to a given need, it is not inadequate to think that this has some bearing in future behavior. Adjusting to existing conditions can imply a learning process which, by definition, is path-dependent. Formally, this translates to having

$$\frac{\partial \psi_{i,t}}{\partial \psi_{i,t-1}} = \gamma_i \in [0,1]\,, \quad i = 1,2,...,l-1 \tag{3.12}$$

where γ_i denotes the degree of path dependence: $\gamma_i = 1$ implies full adjustment and $\gamma_i = 0$ complete path dependence[5]. Our functional form for the dynamics of prepotencies can then be expanded to account for this as follows

$$\psi_{i,t} = \kappa_{i,t}\left(\gamma_i \varphi_{i,t} + (1-\gamma_i)\psi_{i,t-1}\right)\,, \quad ,i = 1,2,...,l-1 \tag{3.13}$$

Demand itself is given by a local or instantaneous optimization as described in what follows. Suppose that at each moment t, preferences are given by a function $B(\mathbf{x}_t, \boldsymbol{\psi}_t)$, which is maximized at each moment subject to a budget constraint. Let $\mathbf{x}_t = \{x_{j,t}\}_{j=1}^{l}$ denote a theoretically-consistent demand system such that

$$x_{i,t} = x_i(\psi_{i,t}, \mathbf{p}_t, y_t) = \arg\max_{\tilde{\mathbf{x}}_t} B(\tilde{\mathbf{x}}_t, \boldsymbol{\psi}_t) \text{ s.t. } y_t \geq \mathbf{p}_t \mathbf{x}_t\,, \quad i = 1,2,...,l \tag{3.14}$$

where $x_{i,t}$ denotes the quantity demanded of good i at time t for given vector of prices $\mathbf{p}_t$, income level y_t and prepotency $\psi_{i,t}$. By theoretically-consistent demand function we imply that the individual demands are homogeneous of degree zero in prices and income and that the demand system as a whole complies with the adding up constraint – $y_t = \sum_j p_{j,t} x_{j,t}$ –, Slutsky's (1915b; 1915a) symmetry – $\partial x_i^h / \partial p_{j,t} = \partial x_j^h / \partial p_{i,t}$ with x_j^h referring to the Hicksian demand function –, and the negative semidefiniteness of the Slutsky matrix, the Hessian of the expenditure function (Deaton and Muellbauer 1980b, ch. 2; Phlips 1983, ch. 3).

5. In eq. 3.12 the derivative is the (direct) *partial* derivative of $\psi_{i,t}$ wrt. $\psi_{i,t-1}$, not the derivative obtained by applying the chain rule when considering that $\psi_{i,t}$ also depends on $\varphi_i(x_{i,t-1})$ and that $x_{i,t-1}$ in turn depends on $\psi_{i,t-1}$.

Going back to the intuition underlying the concept of prepotency, if a higher prepotency implies that the individual has more reasons to tend to a given need, then at a given moment,

$$\frac{\partial x_{i,t}}{\partial \psi_{i,t}} > 0 \tag{3.15}$$

Finally, let our prepotencies-adjustment system be given by the first-order nonlinear autoregressive exogenous model (NARX)

$$\psi_{i,t} = \begin{cases} \kappa_{i,t}\left(\gamma_i \varphi_i\left(x_{i,t-1}(\psi_{i,t-1}, \mathbf{p}_{t-1}, y_{t-1})\right) + (1-\gamma_i)\psi_{i,t-1}\right), & i = 1, 2, ..., l-1 \\ \kappa_{i,t}, & i = l \end{cases} \tag{3.16}$$

where

$$\kappa_{i,t} = \begin{cases} 1\,, & i = 1 \\ 1 - \sum_{h=1}^{i-1} \psi_{h,t}\,, & i = 2, 3, ..., l \end{cases} \tag{3.17}$$

and γ_i denotes the adjustment factor for $\psi_{i,t}$. As discussed before, $\psi_{i,t} \in [0, 1]$ and thus it is assumed that $\varphi_i(x_{i,t-1}) \in [0, 1]$.

The system complies with all the above tenets: prepotencies increase in past realizations of the same and decrease in past consumption and lower-order needs' prepotencies. We then obtain our dynamic demand system, being given by a collection functions for demand and $\{x_{i,t}\}_{i=1}^{l}$ and prepotencies $\{\psi_{i,t}\}_{i=1}^{l}$, with prices ($\mathbf{p}_t$) and income (y_t) assumed to be exogenous.

4.2. Dynamics of the Adjustment Process

Given these definitions and assuming an interior equilibrium, two propositions on the dynamics of the system can asserted as follows:

Proposition 3.11. *The dynamic system has a steady state.*

Proof. At the steady steady state, with $\kappa_{i,t} = \kappa_{i,t-1} = \kappa_i$, $\psi_{i,t} = \psi_{i,t-1} = \psi_i$, $\mathbf{p}_t = \mathbf{p}_{t-1} = \mathbf{p}$ and $y_t = y_{t-1} = y$, $x_{i,t-1}(\psi_{i,t-1}, \mathbf{p}_{t-1}, y_{t-1})$ collapses to $x_i(\psi_i, \mathbf{p}, y) = x_i$ and then

$$\psi_{i,t} = \psi_{i,t-1} = \psi_i = \kappa_i \left(\gamma_i \varphi_i \left(x_i\right) + (1-\gamma_i)\psi_i\right) \Leftrightarrow \tag{3.18}$$

$$\psi_i = \frac{\kappa_i \gamma_i}{1-\kappa_i(1-\gamma_i)} \varphi_i \left(x_i\right) \in [0,1], \qquad i = 1, 2, ...l-1 \tag{3.19}$$

As prices and income are assumed to be exogenous and given that $x_{i,t}(\psi_{i,t}, \mathbf{p}_t, y_t)$, if all $\psi_{j<i,t}$, $j = 1, ..., j-1$ have a fixed point, uniquely determined, $\psi_{i,t}$ will become an autonomous recurrence relation and have a fixed point as well. Given that, by definition, $\psi_{1,t}$ defines an autonomous recurrence relation (holding prices and income fixed), it will have a (single) fixed point, $\psi_1 = \varphi_i(x_i)$. Thus, $\psi_{2,t}$, $\psi_{3,t}$, and all the remaining $\psi_{i,t}$ will have fixed points. Consequently, fixing prices and income, the system has a fixed point, i.e., a steady state. $\square$

Proposition 3.12. *If, (i) $\gamma_i \in (0,1)$; (ii) $\frac{d\varphi_i}{dx_{i,t-1}} \frac{x_{i,t-1}}{\varphi_i(x_{i,t-1})} \in (-1,0)$, $i = 1, 2, ..., l-1$; and (iii) $x_{i,t}(\psi_{i,t}, \boldsymbol{p}_t, y_t) = f(\psi_{i,t}, \boldsymbol{p}_t, y_t) + c$, $c \leq 0$ and with $f(\psi_{i,t}, \boldsymbol{p}_t, y_t)$ being non-separable or at most weakly separable in $\psi_{i,t}$, $i = 1, 2, ..., l$; then the system's steady state is asymptotically stable.*

Proof. A sufficient condition for stability of each fixed point (Elaydi, 2005, pp. 28-9) is that

$$\left| \frac{d\psi_{i,t}}{d\psi_{i,t-1}} \right|_{\psi_{i,t-1}=\psi_i} < 1 \Leftrightarrow \tag{3.20}$$

$$\Leftrightarrow \left. \frac{d\psi_{i,t}}{d\psi_{i,t-1}} \right|_{\psi_{i,t-1}=\psi_i} < 1 \quad \wedge \quad \left. \frac{d\psi_{i,t}}{d\psi_{i,t-1}} \right|_{\psi_{i,t-1}=\psi_i} > -1 \tag{3.21}$$

Assume that

$$\frac{d\varphi_i}{dx_{i,t-1}} \frac{x_{i,t-1}}{\varphi_i(x_{i,t-1})} \in (-1,0) \quad \Rightarrow \quad \frac{d\varphi_i}{dx_{i,t-1}} x_{i,t-1} \in (-\varphi_i(x_{i,t-1}), 0) \tag{3.22}$$

and that $x_{i,t}(\psi_{i,t}, \mathbf{p}_t, y_t) = f(\psi_{i,t}, \mathbf{p}_t, y_t) + k$, $k \leq 0$ and with $f(\psi_{i,t}, \mathbf{p}_t, y_t)$ being non-separable or at most weakly separable in $\psi_{i,t}$.

Then, knowing that, by definition,

$$\frac{d\psi_{i,t}}{d\psi_{i,t-1}} = \kappa_i \left(\gamma_i \frac{d\varphi_i}{dx_{i,t-1}} \frac{dx_{i,t-1}}{d\psi_{i,t-1}} + (1-\gamma_i) \right) < 1 \tag{3.23}$$

one has to show that, at the fixed point,

$$\frac{d\psi_{i,t}}{d\psi_{i,t-1}} = \kappa_i \left(\gamma_i \frac{d\varphi_i}{dx_{i,t-1}} \frac{dx_{i,t-1}}{d\psi_{i,t-1}} + (1-\gamma_i) \right) > -1 \Leftrightarrow \tag{3.24}$$

$$\Leftrightarrow \int \kappa_i \left(\gamma_i \frac{d\varphi_i}{dx_{i,t-1}} \frac{dx_{i,t-1}}{d\psi_{i,t-1}} + (1-\gamma_i) \right) d\psi_{i,t-1} > -\int 1 d\psi_{i,t-1} \Leftrightarrow \tag{3.25}$$

$$\Leftrightarrow \kappa_i \left(\gamma_i \frac{d\varphi_i}{dx_{i,t-1}} x_{i,t-1} + (1-\gamma_i)\psi_{i,t-1} \right) > -\psi_{i,t-1} \Leftrightarrow \tag{3.26}$$

$$\Leftrightarrow \kappa_i \gamma_i \left(\frac{d\varphi_i}{dx_{i,t-1}} x_{i,t-1} \right) > -\psi_{i,t-1}(1+\kappa_i(1-\gamma_i)) \tag{3.27}$$

Evaluating the condition at the fixed point, we have

$$\kappa_i \gamma_i \left(\frac{d\varphi_i}{dx_i} x_i \right) > -\frac{\kappa_i \gamma_i}{1-\kappa_i(1-\gamma_i)} \varphi_i\left(x_i\right)\left(1+\kappa_i(1-\gamma_i)\right) \Leftrightarrow \tag{3.28}$$

$$\Leftrightarrow \left(\frac{d\varphi_i}{dx_i} x_i \right) > -\varphi_i\left(x_i\right) \geq -\frac{1}{1-\kappa_i(1-\gamma_i)} \varphi_i\left(x_i\right)\left(1+\kappa_i(1-\gamma_i)\right) \Leftrightarrow \tag{3.29}$$

$$\Leftrightarrow \frac{1}{1-\kappa_i(1-\gamma_i)}(1+\kappa_i(1-\gamma_i)) \geq 1 \tag{3.30}$$

$$\Leftrightarrow 2\kappa_i(1-\gamma_i) \geq 0 \tag{3.31}$$

which implies that, under the aforementioned conditions, every fixed point is asymptotically stable. □

4.3. Steady-State Effects

In the steady state, demand will be given by

$$x_i = f_i(\{\psi_j\}_{j=1}^{i}, \mathbf{p}, y) \quad i = 1, 2, ..., l \tag{3.32}$$

Demand for good i will then have the following partial derivatives with respect to income y or a given price p_j

$$\frac{\partial x_i}{\partial y} = \frac{\frac{\partial f_i}{\partial y} + \frac{\partial f_i}{\partial \psi_i}\left(\sum_{h=1}^{i-1} \frac{\partial \psi_i}{\partial \psi_h}\frac{\partial \psi_h}{\partial x_h}\frac{\partial x_h}{\partial y}\right)}{1 - \frac{\partial f_i}{\partial \psi_i}\frac{\partial \psi_i}{\partial x_i}} \tag{3.33}$$

$$\frac{\partial x_i}{\partial p_j} = \frac{\frac{\partial f_i}{\partial p_j} + \frac{\partial f_i}{\partial \psi_i}\left(\sum_{h=1}^{i-1} \frac{\partial \psi_i}{\partial \psi_h}\frac{\partial \psi_h}{\partial x_h}\frac{\partial x_h}{\partial p_j}\right)}{1 - \frac{\partial f_i}{\partial \psi_i}\frac{\partial \psi_i}{\partial x_i}} \tag{3.34}$$

If there were no "internalities", the partial derivatives would then be given by

$$\frac{\partial x_i}{\partial y} = \frac{\partial f_i}{\partial y} \tag{3.35}$$

$$\frac{\partial x_i}{\partial p_j} = \frac{\partial f_i}{\partial p_j} \tag{3.36}$$

Here it is possible to understand that the denominator is positive and greater than one, that is, "internalities" might even change the sign of the partial derivative. For instance, in the case of (normal) substitutes, $\partial f_i / \partial p_i < 0$, but the summation will retain the positive sign associated to $\partial x_h / \partial p_i$, $h = 1, ..., i-1$, resulting in $\partial f_i / \partial p_i < \partial x_i / \partial p_i$. The price effects for otherwise normal goods will be, at least, mitigated.

In the case of otherwise positive income effects, it is clear that these will remain positive despite the internalities, being the effect of the lowest order smaller and of the highest order greater than these would be in the absence of melioration. Consider the case a homothetic instantaneous behavior function. Then, at an interior equilibrium,

$$\frac{\partial x_1}{\partial y} = \frac{\frac{\partial f_1}{\partial y}}{1 - \frac{\partial f_i}{\partial \psi_1}\frac{\partial \psi_1}{\partial x_1}} \Leftrightarrow \tag{3.37}$$

$$\Leftrightarrow \varepsilon_{y,1} = \frac{1}{1 - \frac{\partial f_i}{\partial \psi_1}\frac{\partial \psi_1}{\partial x_1}} < 1 \tag{3.38}$$

$$\frac{\partial x_i}{\partial y} = \frac{\frac{\partial f_i}{\partial y} + \frac{\partial f_i}{\partial \psi_i}\left(\sum_{h=1}^{i-1} \frac{\partial \psi_i}{\partial \psi_h}\frac{\partial \psi_h}{\partial x_h}\frac{\partial x_h}{\partial y}\right)}{1 - \frac{\partial f_i}{\partial \psi_i}\frac{\partial \psi_i}{\partial x_i}} \Leftrightarrow \tag{3.39}$$

$$\Leftrightarrow \varepsilon_{y,i} = \frac{1 + \frac{y}{x_i}\frac{\partial f_i}{\partial \psi_i}\left(\sum_{h=1}^{i-1} \frac{\partial \psi_i}{\partial \psi_h}\frac{\partial \psi_h}{\partial x_h}\frac{\partial x_h}{\partial y}\right)}{1 - \frac{\partial f_i}{\partial \psi_i}\frac{\partial \psi_i}{\partial x_i}} \gtreqless 1 \tag{3.40}$$

$$\frac{\partial x_l}{\partial y} = \frac{\partial f_l}{\partial y} + \frac{\partial f_l}{\partial \psi_l}\left(\sum_{h=1}^{l-1} - \frac{\partial \psi_h}{\partial x_h}\frac{\partial x_h}{\partial y}\right) \Leftrightarrow \tag{3.41}$$

$$\Leftrightarrow \varepsilon_{y,l} = 1 + \frac{y}{x_l}\frac{\partial f_l}{\partial \psi_l}\left(\sum_{h=1}^{l-1} - \frac{\partial \psi_h}{\partial x_h}\frac{\partial x_h}{\partial y}\right) > 1 \tag{3.42}$$

In this case, unlike the unit income elasticities that would arise with simple homothetic preferences, we will have an ordering of income elasticities. As $\partial\psi_i/\partial\psi_j$ will decrease (in absolute terms) with increasing x_i and x_h, $h < i$, that is, with higher need satisfaction, while for low income these will be above unity. Given enough income, hence enough x_1, $\varepsilon_{y,2}$ will turn from greater than one to lower than one.

In economic jargon, this implies that at some moment, goods might turn from luxuries to necessities – as asserted in some empirical studies (Banks et al., 1997; Moneta and Chai, 2014). Moreover, income elasticity for the goods satisfying the lowest- and highest-order needs are assuredly below and above one, respectively.

5. An Illustration

The results derived in the previous section will now be graphically illustrated with a three goods example by assuming particular functional forms for preferences and for φ_i. In particular, we will assume that short-run preferences are homothetic and yield short-run price independent (unaffected by other goods' prices) demand functions – in other words, that we have Cobb-Douglas short-run preferences, where the parameters are the prepotencies associated to each good. Then, we obtain

$$x_{i,t} = \frac{y_t}{p_{i,t}}\psi_{i,t}\,, \quad i = 1, 2, 3 \tag{3.1}$$

Furthermore, we define φ_i as

$$\varphi_i(x_{i,t-1}) = (1 + x_{i,t-1})^{-1}\,, \quad i = 1, 2 \tag{3.2}$$

This renders prepotencies corresponding to budget shares, making interpretation easier. From propositions 3.11 and 3.12 we know we will have a steady state and that this will be asymptotically stable. The convergence process of the budget shares is shown in fig. 3.1, with the convergence (stopping) criterion being $|\psi_{1,t-1} - \psi_{1,t}| < \delta \quad \wedge \quad |\psi_{2,t-1} - \psi_{2,t}| < \delta$, $\delta = 10^{-8}$. This and all the remaining figures in this section assume that, whenever fixed, $y = 24$, $p_1 = 1$, $p_2 = 8$ and $p_3 = 16$ and $\gamma_1 = \gamma_2 = 0.25$; additionally, all figures refer to steady state demand functions, apart from fig. 3.1 of course.

Figure 3.1: **Convergence to Steady State**

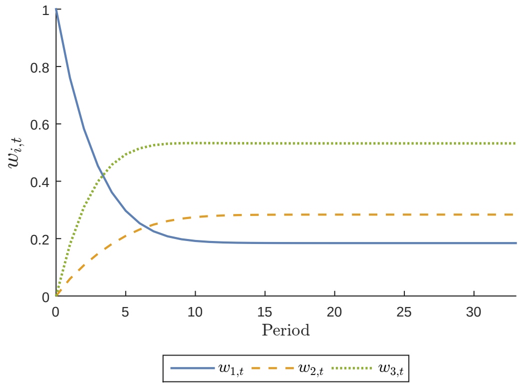


Figure 3.2: **Budget Shares and** p_1

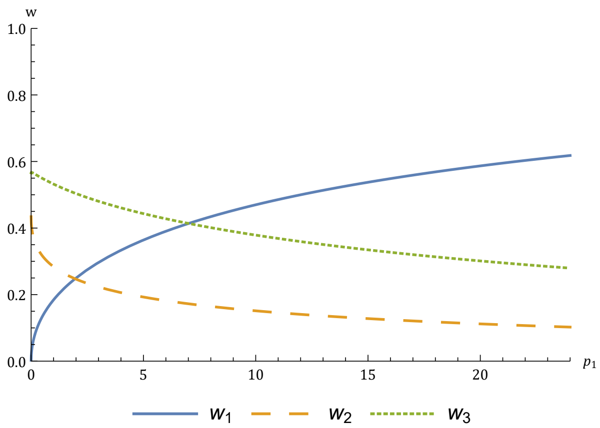


Figure 3.3: **Budget Shares and** p_2

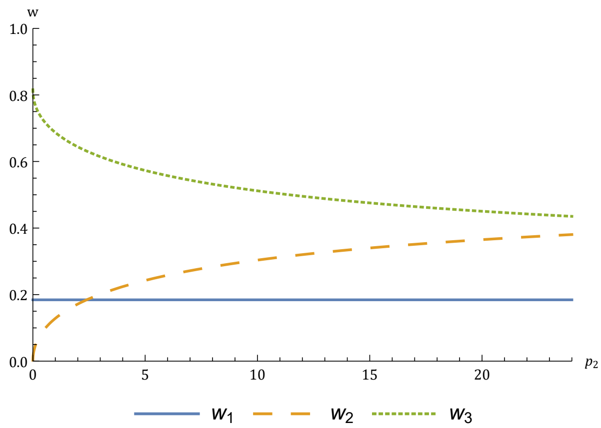


Figure 3.4: **Engel Curves**

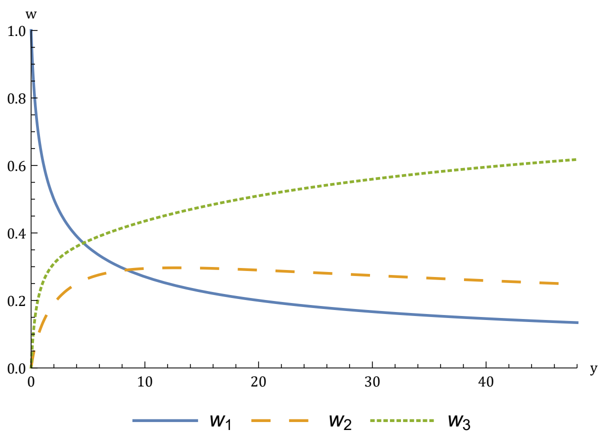
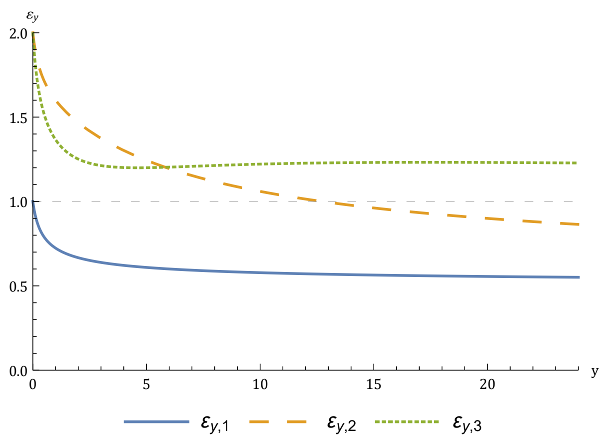


Figure 3.5: **Income Elasticities**



With these functional forms, steady-state budget shares are given by

$$w_i = \psi_i = \frac{1}{2}\frac{p_i}{y}\left(\left(1 + 4\frac{\kappa_i\gamma_i}{1-\kappa_i(1-\gamma_i)}\frac{y}{p_i}\right)^{1/2} - 1\right)\ ,\quad i = 1, 2, ..., l-1 \tag{3.3}$$

$$w_l = \psi_l = \kappa_l \tag{3.4}$$

$$\kappa_i = \begin{cases} 1\ , & i = 1 \\ 1 - \sum_{h=1}^{i-1}\psi_h\ , & i > 1 \end{cases} \tag{3.5}$$

Immediately, it can be seen that $\psi_i(\{p_j\}_{j=1}^{i}, y_t)$, that is, a given budget share depends on income, its own price and the prices of goods satisfying lower needs – but not higher ones, as illustrated in fig. 3.2 and 3.3 – what accounts for the fully flat line in 3.3. In other words, one could say that in this model the price of bread impacts the demand for smartphones, but the price of smartphones has no influence whatsoever on the demand for bread. It can be shown that if p_i is large enough it will negatively affect consumption of all higher-order goods x_j, $j > i$. This steady-state ordered price dependence is a particularly interesting result, which comes from the structure of the melioration process depending on the hierarchy of needs.

Regarding Engel curves, it is clear that these are nonlinear and that goods not associated to the highest-order need will have a decreasing income elasticity with higher income levels. Good 2, as can be seen in fig. 3.5, starts with an income elasticity higher than one which then crosses the unitary threshold at some point, while goods 1 and 3 consistently remain below and above one. Consequently, budget shares for goods associated to needs other than the highest-order one are driven to zero as income increases to infinity.

As in the melioration process higher needs' prepotencies are subject to the independent realization of prepotencies of lower needs, the model is structured according to the Jevonian/Maslovian insight of higher needs becoming prepotent only when lower ones are sufficiently satisfied.

A last thing to notice is that the steady state depends on the adjustment factor γ_i for needs higher than the first. In fact, in order to have a stable steady state, it is not necessary that $\gamma_1 \in (0, 1)$; the interval can be closed, but then it depends on additional conditions. At any rate, steady-state values are not affected by initial conditions, as can be seen in the appendices (both the additional outputs in appendix 3.B and the digital appendices.

The results exhibited for this particular case show that the hierarchical needs (Maslow, 1943, 1987), learning to consume (Witt, 2001; Chai, 2016) and path-dependent endogenous preferences (Pollak, 1970; von Weizsäcker, 1971; Rabin, 2013; Loewenstein et al., 2003) – namely in their melioration version (Herrnstein and Vaughan Jr., 1980; Herrnstein et al., 1993) – can be combined to illuminate the empirical evidence from applied demand research. Here individuals are seen to have path-dependent behavior, adjusting their actions at every period until a reason to do so ceases to exist. Adjustment to "shocks" or permanent changes in exogenous variables is not automatic: it takes time to learn how to react to changing conditions. And, finally, the fact that demand *adjusts* enables yet another mechanism through which differential need satiation can explain Engel curves' nonlinearity, as short-run and long-run demand functions may differ (as in the standard case for "myopic" habits).

6. Final Remarks

Our results suggest that providing a clear behavioral foundation to demand based on need satiation can be the key to explain the nonlinearity of Engel curves. As the income level rises, *ceteris paribus*, individuals have additional purchasing power that they use to increase their satiation in lower needs and, as these become more satiated, higher needs emerge as crucial in influencing behavior. What previously was a luxury is now viewed as a necessity and consumption patterns change completely. Not only can individuals buy better-quality goods to satisfy lower needs but they can also acquire different goods that relate to needs previously beyond their reach. Lifestyles do change (Earl, 1986). However, they are not changed overnight. The emergence of higher needs as prepotent is taken to be the outcome of a gradual process of adjustment to new conditions. A process which reaches an end, characterized by new demand patterns.

When taken at an aggregate level, these varying demand patterns can lead to structural change. This might be the missing piece in accounting for industrial recomposition, as is increasingly suggested[6]. This paper discusses *why* we see demand changing: need satiation

6. E.g., Pasinetti (1981); Foellmi and Zweimüller (2006); Foellmi and Zweimüller (2008); Foellmi et al. (2014); Boppart (2013); Boppart and Weiss (2013); Moneta and Chai (2014); Comin et al. (2015).

and emergence of higher needs. Combining this with meliorating processes, furthermore, tackles the question of demand's path-dependence.

In all, combining a needs-based melioration process even with short-run homothetic preferences is able to instill realism in the way income influences demand when taking into account this adjustment process. Moreover, this model yields asymmetric (non-compensated) price effects, with changes in the prices of goods associated with lower needs influencing to a greater extent demand related to higher needs than the other way around. Demand for goods satisfying higher and lower needs does not differ due to some *ad hoc* parameter, but rather it is endogenously explained by the functionals – here the system – describing behavior, which imposes some ordered asymmetry from the start. More than a mere difference in preference parameters, the difference between expenditure in food and in recreation is due to these needs having disparate, and evolving, prepotencies.

That this explanatory model is not easily amenable to empirical estimation is a limitation assumed from the onset. Obtaining a description of the patterns in the data requires functionals as flexible as possible. Contrastingly, our model imposes a structure where, necessarily, demand functions will differ in form and not only in parameters. Notwithstanding, it does present an hypothesis to understand the behavioral mechanisms underlying both demand short-run path dependence and the nonlinearity of Engel curves.

In theoretical terms, the choice for instantaneous optimization of short-run preferences to the detriment of intertemporal optimization of long-run preferences – a concept which is unwarranted, as Pollak (1976) stresses – implies that we required behavior to be consistent in the short run only. Thus, behavior is subject to a projection bias (Loewenstein et al., 2003) that may lead to time inconsistency. Though arguable, "myopic" behavior seems more supported by data than Beckerian habits (Muellbauer, 1988). Intertemporal choice is still feasible, but the model's setup implies that choices are revised in each period as prepotencies (and, thus, preferences) adjust. This is also one of the strengths of successive optimization with endogenous path-dependent preferences as opposed to the "rational" version, given that in latter, separate budgeting over how much to spend now and how much to save is not possible without a perfectly defined consumption plan for every period in the future (Pollak and Wales, 1995, p. 127).

Lastly, the behavior structure laid out in this paper may also provide some intuition on "Wright's law" (Stigler, 1954, p. 101) – the second half of the 19th century was abundant in economic "law-making" – which can be subsumed in saying that savings are a luxury. Instead of infinite-period optimization, future consumption might be seen as a higher-order need – something that Menger (1871, ch. II) had already pointed out – and savings the product of a instantaneous optimization; appendix 3.C. can also be seen as a sketch of this hypothesis. Alternatively, one can choose to combine intertemporal choice with meliorating/path-dependent preferences. The analytical implications associated to each of these options are left for further research.

7. Appendices

7.1. Appendix 3.A. Digital Appendices

The digital appendices to this paper – a cdf and three pdf files – can be downloaded from the following links

Digital Appendix - CDF:
https://sites.google.com/site/dgduartegoncalves/melioration-and-needs-digital-appendices/Melioration%20and%20Needs.%20Example%201.cdf?attredirects=0&d=1

Digital Appendix - Mathematica code and results - PDF
https://sites.google.com/site/dgduartegoncalves/melioration-and-needs-digital-appendices/Melioration%20and%20Needs.%20Example%201.%20Mathematica%20Code.pdf?attredirects=0&d=1

Digital Appendix - MATLAB code - PDF
https://sites.google.com/site/dgduartegoncalves/melioration-and-needs-digital-appendices/Melioration%20and%20Needs.%20MATLAB%20Code.pdf?attredirects=0&d=1

Digital Appendix Example with Nested Preferences - MATLAB code - PDF
https://sites.google.com/site/dgduartegoncalves/melioration-and-needs-digital-appendices/Melioration%20and%20Needs.%20Example%20with%20Nested%20Preferences.%20MATLAB%20Code.pdf?attredirects=0&d=1

The first two files refer to the example in section 5, showing, respectively, dynamic graphs on convergence and with steady state results – the cdf – and the Wolfram Mathematica code and associated analytical results. In these graphs, the reader can change the values of prices and income in each graph and immediately perceive the changes.

The third and fourth files contain the MATLAB code used to produce fig. 3.1 the remaining figures and table in appendices 3.B. and 3.C.

7.2. Appendix 3.B. Additional Outputs

All figures assume that, when fixed, $y = 24$, $p_1 = 1$, $p_2 = 8$ and $p_3 = 16$, while, $\gamma_1 = \gamma_2 = 0.25$. The figures represent how does demand respond to shocks in the short run – permanent or transient – an also how the convergence process is affected by adjustment factors and initial conditions. A table shows how many periods did it take for the system to comply with the convergence (stopping) criterion, which was defined as $|\psi_{1,t-1} - \psi_{1,t}| < \delta \quad \wedge \quad |\psi_{2,t-1} - \psi_{2,t}| < \delta$, $\delta = 10^{-8}$.

Figure 3.6: **Permanent 50% Income Shock**

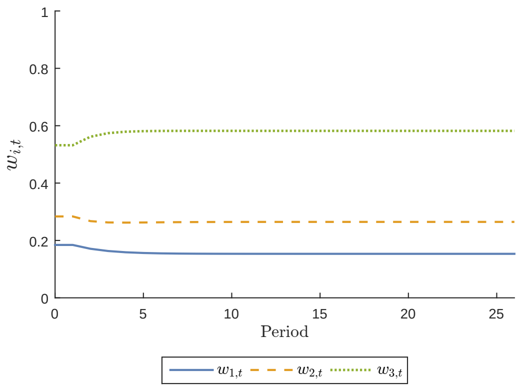


Figure 3.7: **Temporary 50% Income Shock**

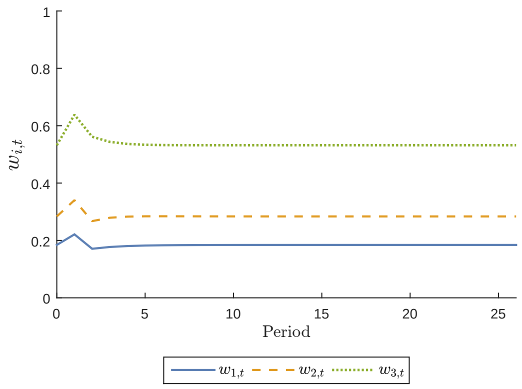


Figure 3.8: **Permanent 50% p_1 Shock**

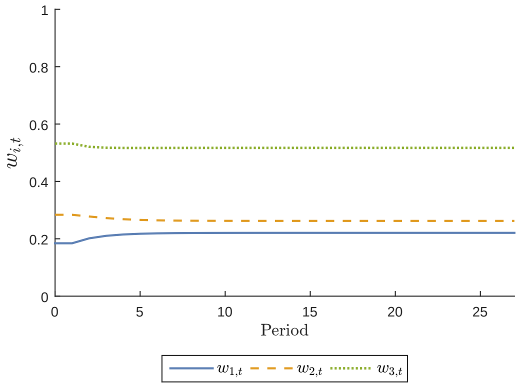


Figure 3.9: **Permanent 50% p_2 Shock**

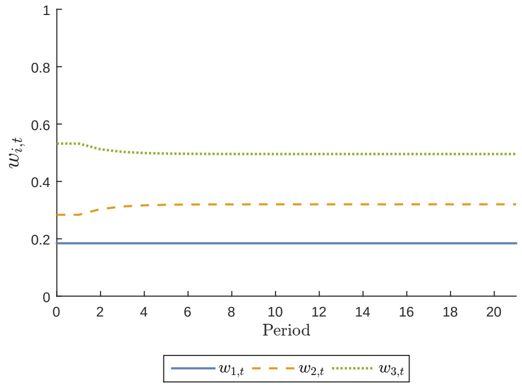


Figure 3.10: **Permanent 50% p_3 Shock**

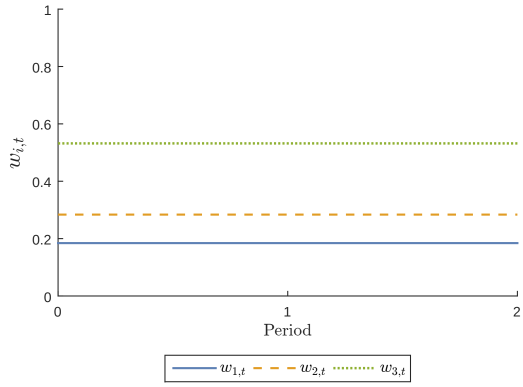


Figure 3.11: **Permanent 0.25 γ_1 Shock**

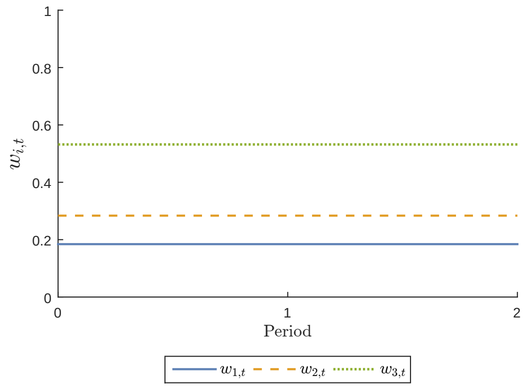


Figure 3.12: **Permanent 0.25 γ_2 Shock**

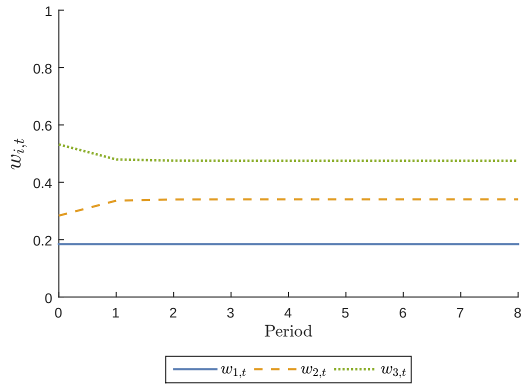


Figure 3.13: **Sensitivity to adjustment factors**

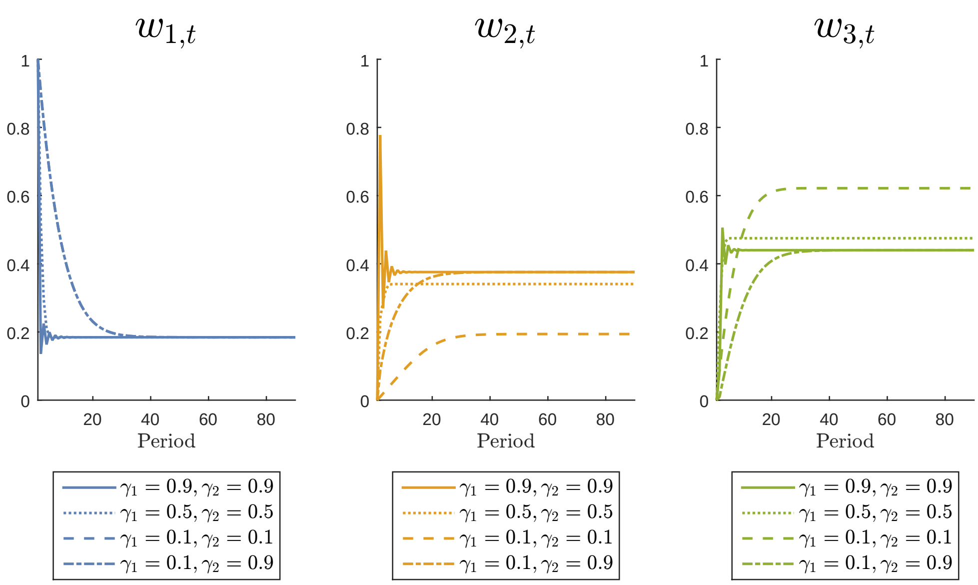


Figure 3.14: **Sensitivity to initial conditions**

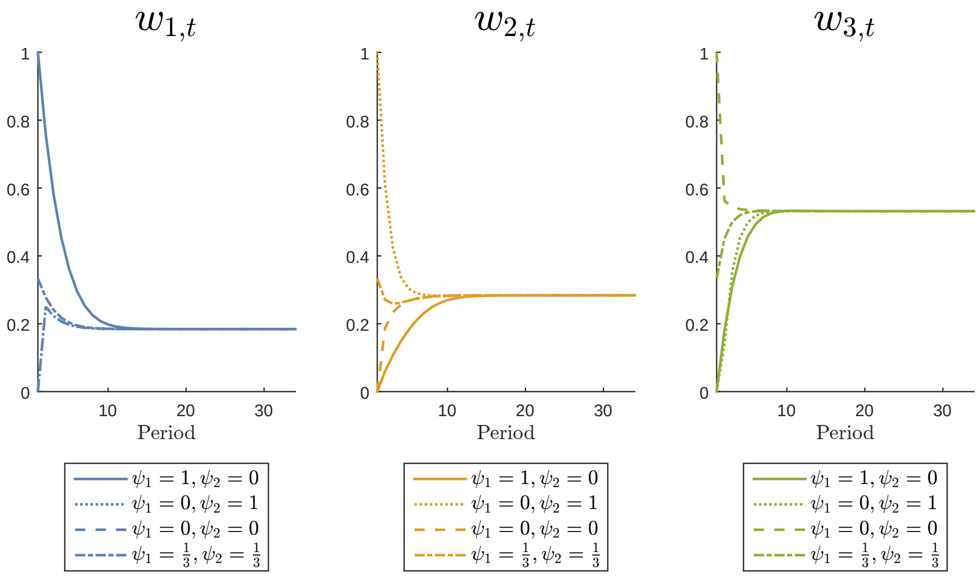


Table 3.1. **Convergence Speed**

γ_1	γ_2	Periods
1/10	1/10	90
1/10	1/2	90
1/10	9/10	90
1/10	1	90
1/2	1/10	38
1/2	1/2	13
1/2	9/10	22
1/2	1	30
9/10	1/10	39
9/10	1/2	39
9/10	9/10	39
9/10	1	41

Number of periods to until complying with the convergence criterion for different values of γ_1 and γ_2.

7.3. Appendix 3.C. An Example with Nested Needs

In this appendix, we present the results for nesting a two-goods model with melioration in a two-needs model. These first-level needs make use of a sigmoid satiation function (cf. chapter II, eq. 2.40) while the lowest need of these two is further decomposed and assumed to have a melioration adjustment process. Specifically, the behavior function assumed has the form

$$B_t = B(x_{1,t}, x_{2,t}, x_{3,t}) = \sigma_1(z_{1,t}) + \sigma_1(z_{1,t})\sigma_2(z_{2,t}) = \tag{3.1}$$

$$= \sigma_1(z_1(x_{1,t}, x_{2,t})) + \sigma_1(z_{1,t}(x_{1,t}, x_{2,t}))\sigma_2(z_2(x_{3,t})) \tag{3.2}$$

where

$$z_{1,t} = x_{1,t}^{\psi_{1,t}} x_{2,t}^{\psi_{2,t}} \tag{3.3}$$

$$z_{2,t} = x_{3,t} \tag{3.4}$$

$$\sigma_1(z_t) = \sigma_2(z_t) = \sigma(z_t) = \frac{z_t}{1 + z_t} \tag{3.5}$$

$$\psi_{1,t} = \gamma_1\varphi(x_{1,t}) + (1 - \gamma_1)\psi_{1,t-1} = \gamma_1(1 + x_{1,t}) + (1 - \gamma_1)\psi_{1,t-1} \tag{3.6}$$

$$\psi_{2,t} = 1 - \psi_{1,t} \tag{3.7}$$

and the resulting preferences are naturally quasiconcave – cf. theorem 3.13.

As preferences over two goods are by definition separable (Gorman, 1959) and $z_{i,t}$ are given by linearly homogeneous functions, there is an exact price aggregator for $z_{1,t}$, $p_{z_{1,t}}$, given by

$$p_{z_{1,t}} = \left(\frac{p_{1,t}}{\psi_{1,t}}\right)^{\psi_{1,t}} \left(\frac{p_{2,t}}{\psi_{2,t}}\right)^{\psi_{2,t}} \tag{3.8}$$

This price aggregator is then used to obtain the expenditure on $z_{1,t}$, given by

$$y_{z,t} = p_{z_{1,t}} z_{1,t} = \begin{cases} y_t & p_{z_{1,t}} + \frac{y_t^2}{y_t - p_{3,t}} \geq 0 \wedge y_t > p_{3,t} \\ \frac{p_{z_{1,t}}}{2p_{z_{1,t}} - p_{3,t}} \left(2p_{3,t} + 2y_t + \sqrt{\frac{p_{3,t}(p_{3,t}+y_t)(2p_{z_{1,t}}+p_{3,t}+2y_t)}{p_{z_{1,t}}}} \right) & 2p_{z_{1,t}} \geq p_{3,t} \wedge \\ & \wedge p_{3,t} \geq 2y_t \wedge p_{z_{1,t}} + \frac{y_t^2}{y_t - p_{3,t}} < 0 \\ \frac{p_{z_{1,t}}}{2p_{z_{1,t}} - p_{3,t}} \left(2p_{3,t} + 2y_t - \sqrt{\frac{p_{3,t}(p_{3,t}+y_t)(2p_{z_{1,t}}+p_{3,t}+2y_t)}{p_{z_{1,t}}}} \right) & (2p_{z_{1,t}} > p_{3,t} \wedge p_{3,t} < 2y_t \wedge \\ & \wedge p_{z_{1,t}} + \frac{y_t^2}{y_t - p_{3,t}} < 0) \vee \\ & \vee \left(2p_{z_{1,t}} \neq p_{3,t} \wedge p_{3,t} \leq y_t\right) \vee \\ & \vee \left(2p_{z_{1,t}} > p_{3,t} \wedge p_{3,t} < 2y_t\right) \vee \\ & \vee (2p_{z_{1,t}} < p_{3,t} \wedge \\ & \wedge p_{z_{1,t}} + \frac{y_t^2}{y_t - p_{3,t}} < 0) \\ \frac{p_{3,t}+2y_t}{4} & \text{if otherwise} \end{cases} \tag{3.9}$$

Then, the budget share $w_{1,t}$ and $w_{2,t}$ are given by the results from the model in described in section 5 (for the first and last good), replacing y_t by $y_{z,t}$ and $w_{3,t}$ will be $1 - w_{1,t} - w'_{2,t}$. This second example serves to show that both approaches, that defined in chapter II and here are perfectly compatible and the results are similar. The model in chapter II, section 5, has a boundary condition where only the lower need is satiated. As in this example the lower need is decomposed into two sub-needs, good 2 (from our present example) shows a budget share increasing in income when this boundary condition is binding, that is, while no quantity of good 3 is consumed. When this boundary condition ceases to be binding, the budget share associated with $z_{1,t} = (x_{1,t}, x_{2,t})$ starts to be decreasing in income and this leads good 2 to exhibit a budget decreasing in income (income elasticity lower than one), as seen in fig. 3.16.

All figures assume that, when fixed, $y = 24$, $p_1 = 1$, $p_2 = 8$ and $p_3 = 16$, while, $\gamma_1 = 0.25$ and, apart from fig. 3.15, these refer to the steady state.

Figure 3.15. **Example 2. Convergence**

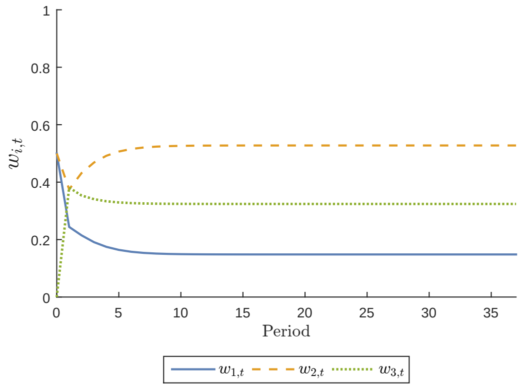


Figure 3.16. **Example 2. Engel Curves**

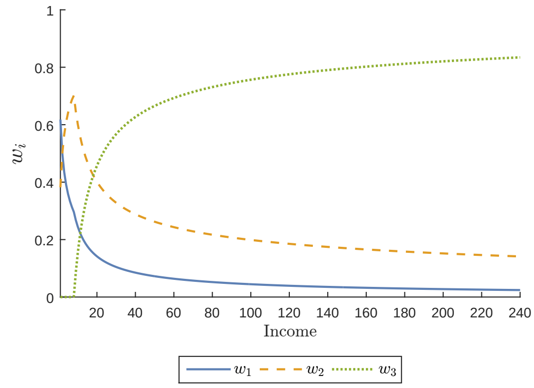
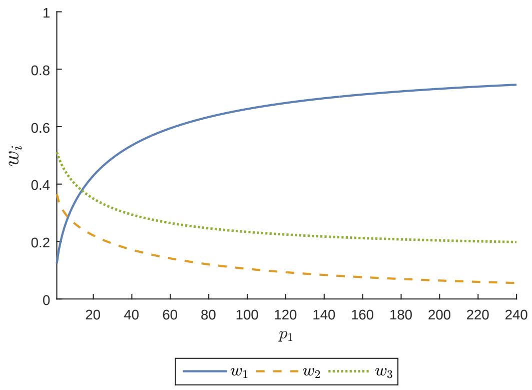
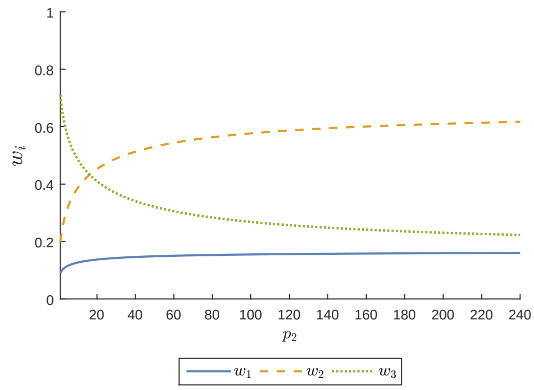


Figure 3.17. **Example 2. Price Effects**

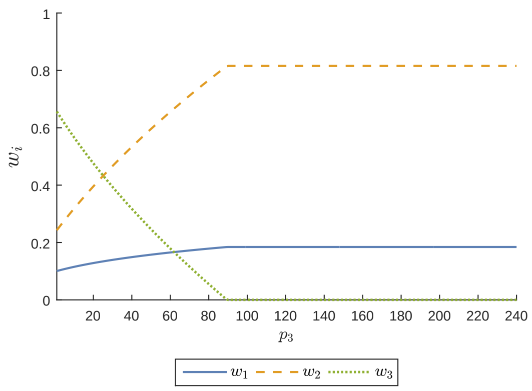
3.17 (i): **Budget Shares and** p_1



3.17 (ii): **Budget Shares and** p_2



3.17 (iii): **Budget Shares and** p_3



Theorem 3.13. *If $\sigma_i(x)$, $i = 1, 2$ and $f_i(\mathbf{x}_j)$, $j = 1, 2$ are concave, non-negative and non-decreasing in $\mathbb{R}_+$ and $\mathbb{R}^n_+$ respectively, then $B = (\sigma_1 \circ f_1)(\mathbf{x}_1) + (\sigma_1 \circ f_1)(\mathbf{x}_1)(\sigma_2 \circ f_2)(\mathbf{x}_2)$ is log-concave and non-negative.*

Proof. Let $\sigma_i(x_i)$ be non-negative, non-decreasing in x_i and concave in $\mathbb{R}_+$ and let $x_i = f_i(\mathbf{x}_i) = f_i(x_{i1}, x_{i2}, ..., x_{in})$, where $f_i : \mathbb{R}^n_+ \to \mathbb{R}_+$ and let f_i be non-negative, non-decreasing in x_{ij}. Then, by the definition of concavity (Boyd and Vandenberghe, 2009, p. 67), we have that

$$\sigma_i(\theta x_i + (1-\theta)y_i) \geq \theta\sigma_i(y_i) + (1-\theta)\sigma_i(y_i) \tag{3.10}$$

$$f_i(\theta \mathbf{x}_i + (1-\theta)\mathbf{y}_i) \geq \theta f_i(\mathbf{x}_i) + (1-\theta) f_i(\mathbf{y}_i) \tag{3.11}$$

with $\theta \in [0, 1]$, $\mathbf{x}_i, \mathbf{y}_i \geq \mathbf{0}$ and $x_i, y_i \geq 0$.
$\sigma_i \circ f_i$ will then be concave iff $(\sigma_i \circ f_i)(\theta\mathbf{x}_i + (1-\theta)\mathbf{y}_i) \geq \theta(\sigma_i \circ f_i)(\mathbf{x}_i) + (1-\theta)(\sigma_i \circ f_i)(\mathbf{y}_i)$, with $\theta \in [0, 1]$, $\mathbf{x}_i, \mathbf{y}_i \geq \mathbf{0}$. Combining the above inequalities,

$$(\sigma_i \circ f_i)\left(\theta\mathbf{x}_i + (1-\theta)\mathbf{y}_i\right) = \tag{3.12}$$

$$= g\left(f_i\left(\theta\mathbf{x}_i + (1-\theta)\mathbf{y}_i\right)\right) \geq \tag{3.13}$$

$$\geq \sigma_i\left(\theta f_i(\mathbf{x}_i) + (1-\theta) f_i(\mathbf{y}_i)\right) \geq \tag{3.14}$$

$$\geq \theta\sigma_i(f_i(\mathbf{x}_i)) + (1-\theta)\sigma_i(f_i(\mathbf{y}_i)) = \tag{3.15}$$

$$= \theta(\sigma_i \circ f_i)(\mathbf{x}_i) + (1-\theta)(\sigma_i \circ f_i)(\mathbf{y}_i) \tag{3.16}$$

If $\sigma_i \circ f_i$, $i = 1, 2$, are concave, then $1 + (\sigma_1 \circ f_1)(\mathbf{x}_1)$ is concave as well concavity is closed under addition. Thus, $B(\mathbf{x}) = (\sigma_1 \circ f_1)(\mathbf{x}_1) + (\sigma_1 \circ f_1)(\mathbf{x}_1)(\sigma_2 \circ f_2)(\mathbf{x}_2) = \left((\sigma_1 \circ f_1)(\mathbf{x}_1) + 1\right)(\sigma_2 \circ f_2)(\mathbf{x}_2)$ is given by the product of two concave functions, resulting in a log-concave function.
As σ_i and f_i, $i = 1, 2$, are non-negative, B will be nonnegative as well.
This concludes the proof. □

IV

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