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HOMOTHETIC PREFERENCES

James Dow
e
Sérgio Ribeiro da Costa Werlang

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Homothetic Preferences

by

James DOW*

and

Sergio Ribeiro da Costa WERLANG**

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Abstract This paper describes properties of upper semi-continuous homothetic preferences. First we give conditions for the existence of an upper semi-continuous representation which is homogeneous of degree one. Then we show that with the additional assumptions of monotonicity or strict convexity, the preference is continuous. Several counterexamples illustrate the tightness of the results.

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* London Business School, Sussex Place, Regents Park, London NW1 4SA, UK. Part of the research for this paper was completed while this author was at the University of Pennsylvania

** Fundacao Getulio Vargas, 10-Andar, Praia de Botafogo 190, Botafogo CEP 22250, Rio de Janeiro, RJ - Brazil. Part of the research for this paper was completed while this author was at IMPA/CNPq, and also visiting the University of Pennsylvania.

0. Introduction

In this paper we study properties of homothetic preference orderings (by the term preference ordering, or simply preference, we mean a complete preordering). We start by considering two definitions which capture the idea of homothetic preferences, and giving conditions under which the preferences may be represented by a utility function which is homogeneous of degree one. Next we explore conditions under which homothetic preferences are continuous. Consider Figure 1, the standard example of a preference ordering which is upper semi-continuous but not continuous (Gorman, 1956). It is clear that this sort of preference is incompatible with homotheticity, but homotheticity and upper semi-continuity alone do not imply continuity (for example see Figure 2). We show, however, that with the additional hypothesis that preferences are either increasing or strictly convex, they are continuous.

The organisation of the paper is as follows. In Section 1, we give two definitions ("homotheticity" and "weak homotheticity") which formalise the notion of homotheticity and we explore their relationship: homothetic preferences are clearly weakly homothetic and we show that under the hypothesis of continuity they are equivalent. An example shows that they are not equivalent in general. The main theorem of the section then gives conditions for the existence of a homogeneous of degree one representation. A further example illustrates the importance of these conditions.

In section 2 we give conditions for homothetic preferences to be continuous. One set of conditions is that they should be upper semi-continuous and increasing. Alternatively we can replace the assumption of increasing preferences by strict convexity if zero is the worst point in the consumption set. Examples show why this last condition is needed, and why convexity but not strict convexity is not sufficient for the result.

1. Homotheticity and Weak Homotheticity

Definition 1.1 A preference $\succsim$ defined on a cone $K \subset \mathbf{R}^n$ is

(i) weakly homothetic if $\forall$ x, y $\in$ K, $\forall$ t > 0, $x \sim y \Rightarrow tx \sim ty$

(ii) homothetic if $\forall$ x, y $\in$ K, $\forall$ t > 0, $x \succsim y \Rightarrow tx \succsim ty$.

Definition 1.2 A preference $\succsim$ defined on a cone $K \subset \mathbf{R}^n$ is

(i) upper semi-continuous if $\forall x \in K$, $\{y \in K \mid y \succsim x\}$ is closed (in K)

(ii) lower semi-continuous if $\forall x \in K$, $\{y \in K \mid y \precsim x\}$ is closed (in K)

(iii) continuous if it is both upper and lower semi-continuous.

Definition 1.3 A preference relation $\succsim$ defined on $K \subset \mathbf{R}^n_+$ is

increasing if $\forall$ x, y $\in$ K, $x \geq y \Rightarrow x \succsim y$.

Definition 1.4 A preference relation $\succsim$ defined on a convex set $K \subset \mathbf{R}^n_+$ is

(i) convex if $\forall$ x, y $\in$ K, $\forall \alpha \in (0,1]$, $x \succ y \Rightarrow \alpha x + (1-\alpha)y \succ y$

(ii) strictly convex if $\forall$ x, y $\in$ K, $x \neq y$, $\forall \alpha \in (0,1)$, $x \succsim y \Rightarrow \alpha x + (1-\alpha)y \succ y$.

Proposition 1.5 Let $\succsim$ defined on a closed cone $K \subset \mathbf{R}^n$ be weakly homothetic and continuous. Then $\succsim$ is homothetic.

Proof Suppose on the contrary that $x \succ y$ and $ty \succsim tx$ for some $t > 0$ and some x, y $\in$ K. By weak homotheticity we cannot have $ty \sim tx$. Therefore, $ty \succ tx$. Without loss of generality let $t > 1$. K is closed and it has a countable basis, hence by Debreu (1954) there exists a continuous representation $U: K \rightarrow \mathbf{R}$ of $\succsim$. For $s \in [1, t]$ define $f(s) = U(sx) - U(sy)$. Then f is continuous with $f(1) > 0$ and $f(t) < 0$. Therefore $\exists\, \bar{s} \in (1, t)$ with $U(\bar{s}x) = U(\bar{s}y) \Rightarrow \bar{s}x \sim \bar{s}y$ which, by weak homotheticity, implies $x \sim y$, a contradiction. QED

Example 1.6 Let $K = \mathbf{R}_+$. Define $U: [0,\infty) \to [0,\infty)$ by $U(\alpha) = \alpha$ for $\alpha < 1$, $U(\alpha) = 1/\alpha + 1$ for $\alpha \geq 1$. U represents an upper semi-continuous, weakly homothetic preference on $\mathbf{R}_+$, but it is not homothetic: $1 \succ ½$, but $1 \prec 2$. The example can easily be extended to $K = \mathbf{R}^n_+$, for instance by setting $V(x_1,..., x_n) = U(\Sigma^n_{i=1}x_i)$.

Theorem 1.7 Let $\succsim$ be defined on a cone $K \subset \mathbf{R}^n$. If

(i) $\succsim$ is upper semi-continuous

(ii) $\forall x \in K, x \succsim 0$

(iii) $\succsim$ is homothetic

then there exists a representation $U: K \to \mathbf{R}$ which is upper semi-continuous and homogeneous of degree one.

Proof If $\forall x \in K, x \sim 0$, $U \equiv 0$ will do. Assume $\exists x \succ 0$. Then $\forall t \in [0,1)$, $x \succ tx$. This is obvious in case $t = 0$. In case $t > 0$ suppose on the contrary that $tx \succsim x$. By homotheticity $t^2x \succsim tx \succsim 0$ and indeed for all $m \geq 1$, $t^mx \succsim x$. Taking the limit as $m \to \infty$ we have $0 \succsim x$ by upper semi-continuity. Thus indeed $x \succ tx$ for all $t \in [0,1)$.

Since $\succsim$ is upper semi-continuous it has an upper semi-continuous representation $V: K \to \mathbf{R}$ (by Rader (1963) and Debreu (1964). Fix some x 0. For $t \geq 0$, define f by $f(t) = V(tx)$. We have shown above that f is strictly increasing.

We now show that $\forall y \in K, \exists r$ such that $y \sim rx$. If $y \sim 0$, $r = 0$ will do. Assume $y \succ 0$. Suppose, on the contrary, that there is no r with $y \sim rx$. Then either $y \succ x$ or $y \prec x$: for the sake of argument suppose $x \succ y$.

Define $\bar{r} = \inf\{r \geq 0 \mid rx \succsim y\}$. By upper semi-continuity $\bar{r}x \succsim y$ so $\bar{r}$ $\succ 0$. If $\bar{r}x \sim y$ we have a contradiction, therefore suppose $\bar{r}x \succ y$. By the definition of $\bar{r}$, $(\bar{r} - \varepsilon)x \prec y$ $\forall \varepsilon \in (0, \bar{r}]$. Thus $\bar{r}$ is a point of discontinuity of f(t) as $f(\bar{r}) > V(y)$ while, for all $\varepsilon \in (0, \bar{r}]$, $f(\bar{r} - \varepsilon) < V(y)$.

By homotheticity, for all $s \in (0, \infty)$, $s\bar{r}x \succ sy$ and $s(\bar{r} - \varepsilon)x \prec sy$ (for $\varepsilon \in (0, \bar{r}]$). Thus f is discontinuous at every point $s \in (0, \infty)$. This is a contradiction since as f is monotonic it has at most a countable number of discontinuities. A similar argument holds if $y \succ x$.

Since $\forall\, y \in K\ \exists\, r \geq 0$ such that $y \sim rx$, we may define $U: K \rightarrow \mathbf{R}$ by $U(y) = f^{-1}(V(y))$. We claim that U is the desired utility function. Because f^{-1} is strictly increasing, U represents $\succsim$. U is upper semi-continuous because V is upper semi-continuous. To show that U is homogeneous of degree one, let $t > 0$. Then

$$V(U(ty)x) = f(U(ty)) = V(ty) \Rightarrow U(ty)x \sim ty \Rightarrow (1/t)U(ty)\, x \sim y.$$

Thus

$$V((1/t)U(ty)\, x) = V(y) \Rightarrow f((1/t)U(ty)) = V(y) \Rightarrow (1/t)U(ty) = f^{-1}(V(y)) = U(y).$$

Therefore $U(ty) = tU(y)$. QED

<u>Example 1.8</u> Let $K = \mathbf{R}^2_+$ and $\succsim$ be defined by $x = (x_1, x_2) \succsim y = (y_1, y_2)$ if $x_2/\|x\| \geq y_2/\|y\|$ (where defined) and $0 \precsim x$, $\forall\, x \in K$. This preference is homothetic and upper semi-continuous, but clearly cannot be represented by a function which is homogenous of degree 1.

<u>Remark 1.9</u> Katzner (1971, 2.3-2) shows that, if preferences are continuous, weakly homothetic and increasing then there exists a representation which is homogenous of degree one. Given Proposition 1.5, this may be viewed as a corollary of Theorem 1.7.

<u>Example 1.10</u> Weakly homothetic, upper semi-continuous preferences can be either convex or increasing without being homothetic. One counterexample is provided by the convex preferences of Example 1.6. The other counterexample is provided by the increasing preferences represented by the following utility function.

Let $K = \mathbf{R}^2_+ \setminus \mathbf{R}^2_{++}$ and s_k be a strictly decreasing sequence with $s_1 = 1$ and $\lim_{k\to\infty} s_k = 0$.

$$
\begin{aligned}
U(s, 0) &= 3 - 1/s && \text{for } s \geq 1 \\
&= \tfrac{1}{2}(s + s_k) && \text{for } s_{k+1} \leq s < s_k \\
U(0, s) &= 2 - 1/s && \text{for } s \geq 1 \\
&= \tfrac{1}{2}(s + s_{k+1}) && \text{for } s_{k+1} \leq s < s_k \\
U(0) &= 0.
\end{aligned}
$$

The preference is weakly homothetic because indifference sets are singletons.

Remark 1.11 The precise role of upper semi-continuity in the relationship between weak homotheticity and homotheticity is an open question (in contrast to continuity, as shown by Proposition 1.5). We conjecture that either of the following sets of conditions, when combined with upper semi-continuity, implies homotheticity:

(i) weakly homothetic, convex and increasing

(ii) weakly homothetic and strictly convex

Note that upper semi-continuity cannot be dispensed with here, as shown by the following example: $K = \mathbf{R}^2_+$, $x \succ y$ if either $x_1 + (x_2)^{1/2} > y_1 + (y_2)^{1/2}$, or if $x_1 + (x_2)^{1/2} = y_1 + (y_2)^{1/2}$ and $x_1 > y_1$.

2. Continuity of Homothetic Preferences

Theorem 2.1 Let $\succsim$ defined on a convex cone $K \subset \mathbf{R}^n_+$ be upper semi-continuous, homothetic and increasing. Then $\succsim$ is continuous.

Proof Let U be an upper semi-continuous, homogeneous of degree one representation of $\succsim$ (Theorem 1.7). By assumption U is increasing. Suppose that U is not continuous. Then since U is upper semi-continuous, there exists a sequence $\{x_n\}$ such that $x_n \to x \neq 0$ and $U(x_n) \to L < U(x)$.

Let $t \in (0,1)$: as $x_n \to x$, for n large enough $x_n \in (\{tx\} + \mathbf{R}^n_+) \Rightarrow U(x_n) \geq tU(x)$. Take a strictly increasing sequence of n's such that $\forall\, t \in (0,1)$, $U(x_{n_t}) \geq tU(x)$. Then $x_{n_t} \to x$ and $U(x_{n_t}) \geq tU(x) \Rightarrow \lim_{t\to 1} U(x_{n_t}) \geq \lim_{t\to 1} tU(x) = U(x)$, a contradiction. QED

Theorem 2.2 Let $\succsim$ defined on $K = \mathbf{R}^n_{++} \cup \{0\}$ be upper semi-continuous, homothetic and strictly convex, with $\forall\, x \in K$, $x \succsim 0$. Then $\succsim$ is continuous.

Proof We must show that $\{y \in K \mid y \precsim x\}$ is closed for all $x \in K$. Suppose not. Then there exists a sequence $y_n \to y$ such that $x \succsim y_n$ and $y \succ x$. By Theorem 1.7, there is an upper semi-continuous, homogeneous of degree 1 utility function U which represents $\succsim$. Since $U(y) > U(x)$ and $U(ty) = tU(y)$, there is $t < 1$ so that $ty \succ x$. Choose a basis $\{z_1, ..., z_n\} \in \mathbf{R}^n_{++}$ with $z_i \geq y$. Note that strict convexity of preferences ensures $U(z_i) > 0$. Thus, we may also require $z_i \succ x$ by replacing z_i by $[1 + U(x)/U(z_i)]z_i$ if necessary. Clearly the z_i may also be chosen so that y is a linear combination of the z_i with strictly positive weights.

Consider the convex hull of $\{ty, z_1, ..., z_n\}$. By construction of the z_i, y is in the interior of the convex hull. Furthermore, convexity of preferences implies that all points in the convex hull are strictly preferred to x. But this is impossible since $y_n \to y$. QED

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Remark 2.3 The theorem remains true for $K = \mathbf{R}^n_+$ and the proof is essentially unchanged except that the case where y is in boundary of $\mathbf{R}^n_+$ requires a more careful choice of z_i. Note that $K = \mathbf{R}^n_+$ rules out some cases of interest, eg Cobb-Douglas preferences.

Example 2.4 To see why strict convexity is needed, consider preferences defined on $\mathbf{R}^2_+$ represented by $U(x_1, x_2) = 0$ if $x_1 \neq x_2$, $U(x_1, x_2) = x_1$ if $x_1 = x_2$. It is homothetic, upper semi-continuous and convex, but not continuous.

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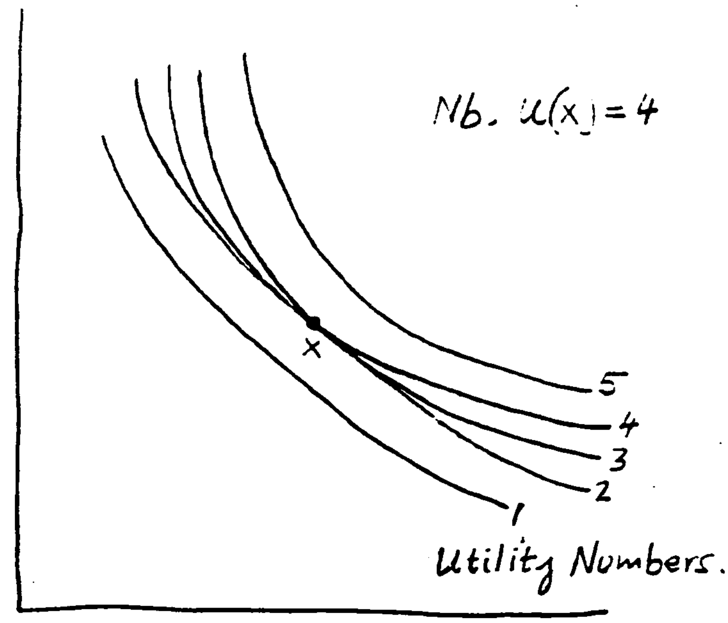

Figure 1

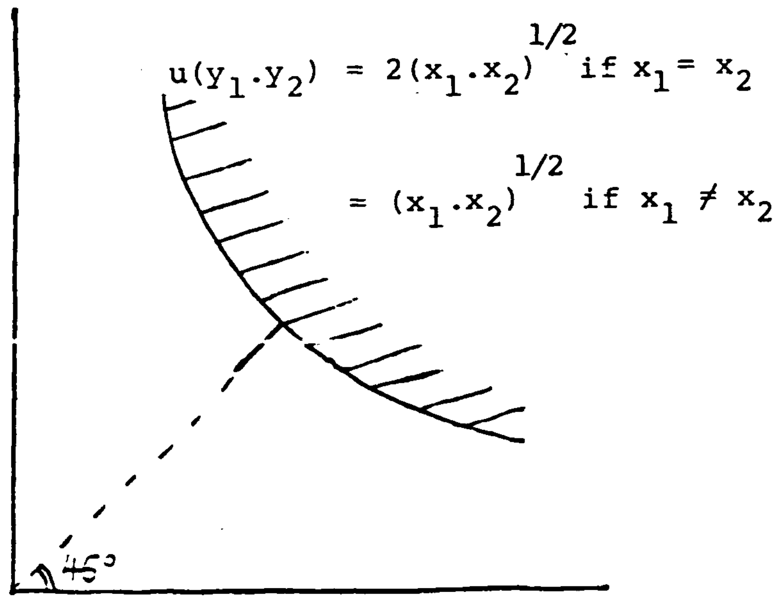

Figure 2

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(a partir do nº 100)

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MARIO HENRIQUE SIMONSEN
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