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A note on continuously decomposed evolving exchange economies

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A Note on Continuously Decomposed Evolving Exchange Economies

MARCO LEHMANN-WAFFENSCHMIDT

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A Note on Continuously Decomposed Evolving Exchange Economies

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Abstract:

It is routine to demonstrate in the exchange economy framework that small changes of individual preferences and endowments always result in small changes of the derived excess demand functions as one should expect. Though being as desirable for reasons of the consistency of the whole approach, however, a precise proof of the converse direction so far is still open to question. The present paper shows that it is actually true. We use a decomposition method for aggregate excess demand functions developed by Mas–Colell which is derived from the well-known decomposition method developed by Sonnenschein and perfected by Debreu and Mantel. Our result fills in a notorious gap in the line of economic justification usually given for this decomposition method.

JEL-Classification: C63, D11, D50

Keywords: continuous decomposition, aggregate excess demand

1 Introduction

It is not hard to prove that continuously changing preferences and endowments of the agents of an exchange economy always lead, as one naturally expects, to continuous changes of the derived aggregate excess demand functions (see e.g. Mas–Colell, 1985, Prop. 2.7.2). The converse direction, however, though seeming as natural, has not yet been verified. In other words, the following is still open to question: can any slightly changing aggregate *excess demand function* be derived from some slightly changing *exchange economy* specified by preferences and initial endowments?

Evidently, an analysis of this question is intimately linked to feasible *decomposition methods* which assign some exchange economy with finitely many agents to any given excess demand function so that the economy's derived excess demand function equals the given function up to a neighborhood of the boundary of the price space (for surveys see e.g. Shafer/Sonnenschein, 1982; Mas–Colell, 1985, p. 242). As every theoretical economist knows Sonnenschein, Debreu, and Mantel have provided compelling decomposition methods in the early seventies. However, the revealed indeterminateness of the equilibrium framework which lies at the heart of economic theory has upset the whole profession. Due to this it is obviously of paramount interest how meaningful this classical type of decomposition method is from the economic viewpoint.

Earlier research work has given answers in the positive (see e.g. Kirman/Koch 1986, Koch 1987, 1989, Hildenbrand/Kirman 1988, Hildenbrand 1999). In fact these studies show that the classical decomposition method is surprisingly flexible. More specifically this means that it is possible to impose additional plausible requirements on the exchange economy to be constructed by merely slightly modifying the classical decomposition method.

Amazingly, however, it has not yet been verified whether it is true that neighboring economies are assigned to neighboring excess demand functions. Clearly, lacking this prerequisite any decomposition method appears to be highly artificial and unsatisfactory.

In this study we will check this fundamental property. More precisely, we are dealing with the variant of the classical decomposition method which has been proposed by Mas–Colell (1985, Proposition 5.5.8). To fix ideas let us reformulate our leading question in a more formal way:

given any continuous one-parametrization (or say homotopy, family, perturbation, or evolution)

$$(f_t)_{t\in[0,1]}$$

of aggregate excess demand functions, is there a *continuous* one-parametrization of *exchange economies*

$$(E_t)_{t\in[0,1]}$$

so that for any $t \in [0,1]$ the excess demand function derived from the t-state economy E_t equals f_t up to a neighborhood of the boundary of the price space *and*, moreover, the equilibrium set of E_t precisely equals the zero set of f_t?

We will show that the affirmative answer is true. More specifically, our procedure will be to verify that for any admissible continuous one-parametrization

$$(f_t)_{t\in[0,1]}$$

of excess demand functions the induced one-parametrizations of the addressed constructions by Mas–Colell *are also continuous*. Thus, loosely speaking, we will prove the continuity of a 'one-parametrized version of Mas-Colell's proof'.

2 Notational Preliminaries

In order to facilitate references to Mas-Colell's constructions in the sequel we will keep to the notations used there as closely as possible.

There are l commodities. The price space is denoted by S, where S is the strictly positive, boundaryless part $S^{l-1} \cap \mathbb{R}^l_{++}$ of the $(l-1)$-unit sphere S^{l-1} in $\mathbb{R}^l$. Let ∂S denote the boundary of $\overline{S}$. Given a small $\epsilon > 0$ the symbol S_ϵ denotes the 'open inner subspace' $\{p \in S | p >> \epsilon e\}$ of S, where e denotes the l-vector with all components $e_i = 1$. For two l-vectors x and y the symbol $x << y$ means that $x_i < y_i$ for all $i = 1, \ldots, l$. Let e^i denote the i-th unit vector of $\mathbb{R}^l$. $p^2_{b,sc}$ denotes the space of C^2-preference relations $\succsim$ on the commodity space $\mathbb{R}^l_{++}$ which are monotone, differentiable, strictly convex, and which satisfy the usual boundary (continuity) condition: for any $x \in \mathbb{R}^l_{++}$ the upper contour set $\{z \in \mathbb{R}^l_{++} | z \succsim x\}$ is closed in $\mathbb{R}^l$ (Mas–Colell, 1985, 2.3.16).

It still remains to specify the respective concepts of nearness of excess demand functions, preference relations, and initial endowments for qualifying changes as "small" or "continuous". Following the lines of Mas–Colell *nearness of individual preference relations* is defined by nearness of the representing direct utility functions, which in turn is derived in the usual way from C^0-uniform convergence on compacta. *Nearness of excess demand functions* will be defined in this study by C^0-uniform convergence *on the whole* of the price space S. Actually, there is nothing unreasonable with this convention since it just rules out situations where there are non-vanishing deviations of function values – even if the critical arguments run to the boundary of the domain. Finally, nearness of initial endowment vectors is obvious.

3 The Result

After these preparations we can state our main result:

Theorem: *Let*

$$\begin{aligned}(f_t)_{t\in[0,1]} : S \times [0,1] &\longrightarrow \mathbb{R}^l \\ (p,t) &\mapsto f_t(p)\end{aligned}$$

be a continuous one-parametrization such that, moreover, the family $(f_t)_{t\in[0,1]}$ *is uniformly convergent on the whole domain* S *(and not only on compacta). For any* $t \in [0,1]$ *the function* $f_t(-)$ *is an excess demand function. That means* $f_t(-)$ *is a tangential* C^3*-vector field on* S *and, furthermore, fulfills the familiar boundary properties*

(i) $\forall_{p\in S}\ \ f_t(p) \geq -ke$ *for some constant* $k \in \mathbb{R}_+$

(ii) if $p^m \longrightarrow p \in \partial S \Longrightarrow ||f_t(p^m)|| \longrightarrow +\infty$.

Then for any $\epsilon > 0$ *one can find a continuous one-parametrization of exchange economies with* l *agents*

$$\begin{aligned}(E_t)_{t\in[0,1]} : \{1,2,\ldots,l\} \times [0,1] &\longrightarrow p^2_{b,sc} \times \mathbb{R}^l_{++} \\ (i,t) &\mapsto (\succsim_{i,t}, \omega_{i,t})\end{aligned}$$

such that the derived excess demand function of any t-state economy

$$\begin{aligned}E_t : \{1,2,\ldots,l\} &\longrightarrow p^2_{b,sc\times\mathbb{R}^l_{++}} \\ i &\mapsto (\succsim_{i,t}, \omega_{i,t})\end{aligned}$$

is equal to f_t *on* S_ϵ*, and, moreover,* p *is an equilibrium for* E_t *if and only if it is a zero of* f_t.

Remark: To call it to the reader's mind the assumption of C^0-uniform convergence on the whole of S just means that the graphs of any two excess demand functions $f_{i,t}$ and $f_{i,t'}$ are close when t and t' are close. Notice further that the last statement of the Theorem means that the given one-parametrization of excess demand functions is *equivalent with respect to equilibria* to the one-parametrization of associated exchange economies. This holds true even though the derived excess demand functions may differ from the given functions on a neighborhood of the boundary of S.

Proof: Our procedure will be to verify that the given one-parametrization $(f_t)_{t\in[0,1]}$ induces *continuous* one-parametrizations of the relevant constructions in the proof of Proposition 5.5.8 by Mas–Colell (1985, pp. 197–201).

(I) Accordingly, let us in the first part of our proof summarize the crucial steps of this proof. (In the sequel all references and citations in citation marks refer to Proposition 5.5.8 and its proof by Mas–Colell, 1985). For the sake of better compatibility let us identify the excess demand function f from Mas–Colell's Proposition 5.5.8 with the initial function f_0 of our one-parametrization $(f_t)_{t\in[0,1]}$. Consequently, all following constructions using utility functions will also receive an additional sub-index 0.

On page 200 an *indirect utility function*

$$u_{i,0} : \mathbb{R}^l_{++} \longrightarrow \mathbb{R}$$

for each of the l agents is provided which is C^2, logarithmically homogeneous, and has the further crucial property

$$^{*)}\forall_{p\in\mathbb{R}^l_{++}} \quad \partial u_{i,0}(p) << 0, \text{ and}$$

$$\partial^2 u_{i,0}(p) \text{ is positive definite.}$$

In "step 1" (pp. 197–198) a canonical construction is provided which associates a unique *direct* utility function, which we will denote by

$$\vartheta_{i,0} : \mathbb{R}^l_{++} \longrightarrow \mathbb{R},$$

with each indirect utility function $u_{i,0}$. Clearly, each $\vartheta_{i,0}$ represents a preference relation $\succsim_{i,0}$ from $p^2_{b,sc}$ (for verifications see "step 1"). Thus we also may speak of an exchange economy when we are given the agents' indirect, or direct, utility functions instead of their explicit preference relations. Furthermore, each agent receives an initial endowment bundle $\omega_{i,0} = ke^i$

where the common scale factor $k \in \mathbb{R}_+$ has to be chosen large enough so that each indirect utility function $u_{i,0}$ fulfills property $^{*)}$ (see below in this study paragraph (II), 2). Actually the exchange economy $(u_{i,0}, ke^i)_{i=1}^l$, or $(\vartheta_{i,0}, ke^i)_{i=1}^l$, has the desired properties: its derived excess demand function coincides with the prescribed C^3-vector field $f_0 : S \longrightarrow \mathbb{R}^l$ on S_ϵ, and the set of equilibria of the economy is equal to the set of zeroes of f_0 (see pp. 200–201 for verifications).

(II) Let us now start the main part of our proof. We will proceed along the following lines: the decomposition into l agents' (in)direct utility functions will be maintained. **In step (1)** we will verify for each agent that the given continuous one-parametrization

$$(f_t)_{t\in[0,1]}$$

leads to a *continuous* one-parametrization $(u_{i,0})_{t\in[0,1]}$ of the associate *indirect utility function*. **In step (2)**, agent i's initial endowment vector $\omega_{i,t}$ will be *held fixed* at ke^i for any t. From the verifications on pp. 200–201 it follows directly that for any $t \in [0,1]$ the t-state economy $(u_{i,t}, ke^i)_{i=1}^l$ generates f_t on S_ϵ, i.e. the excess demand function which is derived from this economy equals f_t on S_ϵ. In addition, the set of equilibria of the t-state economy equals the set of zeroes of f_t. Thus our proof will be completed if it will be shown **in step (3)** that also the *associate one-parametrization of exchange economies*

$$\begin{aligned}(E_t)_{t\in[0,1]} : \{1,2,\dots,l\} \times [0,1] &\longrightarrow p^2_{b,sc} \times \mathbb{R}^l_{++} \\ (i,t) &\mapsto (\succsim_{i,t}, \omega_{i,t}) = (\succsim_{i,t}, ke^i)\end{aligned}$$

is *continuous*. Due to Definition 2.4.1 by Mas–Colell this is equivalent to the continuity of the *associate* one-parametrization

$$(E'_t)_{t\in[0,1]} : (i,t) \mapsto (\vartheta_{i,t}, ke^i)$$

of *direct utility functions and initial endowment vectors*.

(1) Let us start now with our **first step** where we have to verify that for each agent i the given continuous one-parametrization $(f_t)_{t\in[0,1]}$ produces a *continuous* one-parametrization

$$(u_{i,t})_{t\in[0,1]}$$

of the *indirect utility* function (see in Mas–Colell's book "step 3")

$$\begin{aligned} u_{i,0} : \mathbb{R}^l_{++} &\longrightarrow \mathbb{R} \\ p &\mapsto \frac{1}{2}\hat{v}_i(p) + \frac{1}{2}u(p) + \frac{1}{k}\hat{f}_{i,0}(p) \end{aligned}$$

The "ingredients" of $u_{i,0}$ are defined as follows:

(i) (see "step 2")

$$\begin{aligned} \hat{v}_i : \mathbb{R}^l_{++} &\longrightarrow \mathbb{R} \\ p &\mapsto \sum_{j=1}^{l} a_{ji}(-\ln((Ap)_j)) \end{aligned}$$

where A is a nonsingular matrix with strictly positive entries, row and column sums equal to one, and generic entry a_{ji}.
Actually, $\hat{v}_i$ has property $^{*)}$ (for verifications see p. 199), and is logarithmically homogeneous.

(ii) (see "step 3")

$$u : \mathbb{R}^l_{++} \longrightarrow \mathbb{R}$$

is C^∞, convex, logarithmically homogeneous, and has the following additional properties:

(1) $\partial u(p) << 0$ for all $p \in \mathbb{R}^l_{++}$

(2) u is a proper mapping

(3) $u(p) = -\ln(pe) \iff \frac{1}{||p||}p \in S_\mu$ for some real positive $\mu < \epsilon$

(4) $\partial^2 u(p)$ is positive definite at any p with $\frac{1}{||p||}p \in S \backslash S_\mu$

(Property (1) together with (4) fulfills 'almost' property $^{*)}$ from above.)

(iii) (see "step 3")
Without loss of generality we can assume that
$\{p \in S | f_0(p) = 0\} \subset S_\epsilon$. Now

$$\begin{aligned} \hat{f}_0 : S &\longrightarrow \mathbb{R}^l \\ p &\mapsto \eta(p)[\alpha(p)f_e(p) + (1-\alpha(p))f_0(p)] \end{aligned}$$

where $f_e(p) = \left(\frac{1}{pe}\right) e - p$, and α and η are C^3-differentiable gluing functions from S to $[0,1]$ such that

$$\begin{aligned} \alpha|_{S_{2\mu}} &\equiv 0 \ \text{ and} \\ \alpha|_{S\backslash S_\mu} &\equiv 1 \ \text{ for some real positive } \mu < \epsilon\text{, and} \\ \eta|_{S\backslash S_{\mu/2}} &\equiv 0 \ \text{ and } \ \eta|_{S_\mu} \equiv 1. \end{aligned}$$

In other words, $\hat{f}_0$ modifies f_0 near the boundary of S into a C^2 vector field with the following properties:

(a) $\hat{f}_0|_{S_\epsilon} = f_0|_{S_\epsilon}$

(b) $e\hat{f}_0(p) \geq 0$ if $p \in S\backslash S_\mu$,
and $\hat{f}_0(p) = 0$ if $p \in S\backslash S_{\mu/2}$.

(c) $p \in S_\mu$ and $\hat{f}_0(p) = 0 \Longrightarrow p \in S_\epsilon$.

(There is a $\mu < 1/2\epsilon$ admitting these properties (see p. 199).)
Putting $\hat{f}_0(p) = \hat{f}_0\left(\frac{p}{||p||}\right)$ one can naturally view $\hat{f}_0$ as defined *on the whole* $\mathbb{R}^l_{++}$. The constant common *scale factor* k will be explained below in step (2). To summarize, agent i's indirect utility function $u_{i,0}$ is only in its *third summand* $(1/k)\hat{f}_{i,0}(p)$ dependent on the given function f_0.

(2) In this step we are going to demonstrate that the given continuous one-parametrization $(f_t)_{t\in[0,1]}$ leads to a continuous *one-parametrization* of agent i's *indirect utility function* $(u_{i,t})_{t\in[0,1]}$ with

$$\begin{aligned} u_{i,t}(p) = \frac{1}{2}&\left[\sum_{j=1}^{l} a_{ji}(-\ln((Ap)_j))\right] + \frac{1}{2}u(p) \\ &+ \frac{1}{k}\eta(p)\left[\alpha(p)\left(\frac{1}{pe}e - p_i\right) + (1-\alpha(p))f_{i,t}(p)\right] \end{aligned}$$

Due to the overall uniform convergence the given continuous one-parametrization $(f_t)_{t\in[0,1]}$ clearly entails a *continuous* one-parametrization $(u_{i,t})_{t\in[0,1]}$ of agent i's indirect utility function such that for any $t \in [0,1]$ the map $u_{i,t}$ satisfies property $^{*)}$ from the beginning of this proof if k is chosen appropriately large. Analogously to the corresponding argument on p. 200 there is no difficulty with this choice because for all $t \in [0,1]$ $\quad \hat{f}_{i,t}|_{s\backslash s_{\mu/2}} \equiv 0, \quad \hat{f}_{i,t}$ is C^2, and $(\hat{f}_{i,t})_{t\in[0,1]}$ is *continuously* one-parametrized over the *compact* interval $[0,1]$.

(3) It still remains to show that the canonically associated one-parametrization of agent i's *direct utility function* $(\vartheta_{i,t})_{t\in[0,1]}$ is also continuous. The method of associating a unique function $\vartheta_{i,t}$ to each function $u_{i,t}$ is provided in "step 1", pp. 197–198. (Note, however, that *there* v denotes the *indirect* utility, and u the *direct* utility function, whereas *here* we maintain the notations u_i for agent i's indirect and ϑ_i for his associate direct utility function.)

$$\vartheta_{i,t} : \mathbb{R}^l_{++} \longrightarrow \mathbb{R}$$

is given by

$$-\vartheta_{i,t}(x) := -u_{i,t}(p_{i,t}(x))$$

where $p_{i,t}(x)$ maximizes the function $-u_{i,t}$ on the 'budget set' $B_x := \{p \in \mathbb{R}^l_{++} | px \leq 1\}$. Actually, the maximizer is *unique*, and $p_{i,t}$ is C^2 (see "step 1", p. 198). Consequently, the one-parametrization $(\vartheta_{i,t})_{t\in[0,1]}$ is continuous if the one-parametrization

$$\begin{aligned} (p_{i,t})_{t\in[0,1]} : \mathbb{R}^l_{++} \times [0,1] &\longrightarrow \mathbb{R}^l_{++} \\ (x,t) &\mapsto p_{i,t}(x) \end{aligned}$$

is continuous.

To show this let us choose an arbitrary point (x^0, t^0) and an arbitrary sequence (x^m, t^m) from $\mathbb{R}^l_{++} \times [0,1]$ which converges to (x^0, t^0). In order to ensure the continuity of $(p_{i,t})_{t\in[0,1]}$ we have to make sure that

$$||p_{i,t^0}(x^0) - p_{i,t^m}(x^m)||$$

converges to zero. But this is clear from the definition and the uniqueness of $p_{i,t}(-)$ due to the fact that the sequence of budget sets B_{x^m} is Hausdorff convergent to B_{x^0}, and due to the assumed overall uniform continuity of the one-parametrization $(u_{i,t})_{t\in[0,1]}$, $\;i = 1, \ldots, l$.

This completes the proof of our Theorem. □

4 Conclusions

We have shown that Mas–Colell's modification of the well-known decomposition method for aggregate excess demand functions developed and perfected by

Sonnenschein, Debreu, and Mantel in fact satisfies the basic requirement of continuity. In other words we have proved that this decomposition method assigns neighboring exchange economies to neighboring excess demand functions. Thus our result fills in an obvious gap in the line of economic justification usually given for this type of decomposition method.

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