The Jevons Double Coincidence Condition and Local Uniqueness of Money: An Example

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October 28, 2009
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WORK IN PROGRESS. PRELIMINARY. NOT FOR QUOTATION

Abstract

Jevons's double coincidence of wants condition is derived as the result of household level transaction costs in general equilibrium where N commodities are traded at $\frac{1}{2}N(N-1)$ commodity-pairwise trading posts. Each household experiences a set-up cost on entering an additional trading post. Budget constraints are enforced at each trading post separately implying demand for a carrier of value between trading posts, commodity money. General equilibrium consists of prices so that each trading post clears. Existence and local uniqueness of commodity money in equilibrium can follow from the scale economy implied by the household set-up cost.

JEL Classification: C62, D50, E40

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Andreu Mas-Colell and Esther Silberstein

During the academic year 1978-79, my family and I spent a delightful year living in Berkeley on a Guggenheim Fellowship. Our house on the Northside was a few blocks from Andreu and Esther's and our children were close enough in age to enjoy playing together. There was some discrepancy in our schedules — my workday started around 8:00 AM and ended at 5:00 PM; Andreu's started about noon and ended after we were all asleep. Nevertheless there was ample time for amiable instructive conversations together. It was a particular joy — three decades later — to join in Andreu's birthday party in Barcelona.

In Berkeley in the 1970s, between conversations with Andreu, the focus of my research was to bridge the gap between monetary theory and the Arrow-Debreu general equilibrium model. That's the topic of the article below.

1 Introduction

Jevons (1875) observes:

> "[In monetary] sale and purchase ... one of the articles exchanged is intended to be held only for a short time, until it is parted with in a second act of exchange. The object which thus temporarily intervenes in sale and purchase is money. At first sight it might seem that the use of money only doubles the trouble, by making two exchanges necessary where one was sufficient; but a slight analysis of the difficulties inherent in simple barter shows that the balance of trouble lies quite in the opposite direction...
>
> "The first difficulty in barter is to find two persons whose disposable possessions mutually suit each other's wants. There may be many people wanting, and many possessing those things wanted; but to allow an act of barter, there must be a double coincidence, which will rarely happen"

Jevons' statement seems precisely correct, but we should recognize how completely it is at odds with a conventional Arrow-Debreu general equilibrium model, Arrow and Debreu (1954), Debreu (1959).

In the Arrow-Debreu model, there are no transaction costs. Each agent has goods he is trying to sell — goods he doesn't want. There is no reason why he should decline — at prevailing prices — to accept one good he doesn't want in exchange for another he doesn't want. In a model without transaction costs, there is no reason at all. In a model with linear transaction costs, he should be willing to make such a trade at a discount reflecting the costs of exchange. And how does money come into the array — a commodity asymmetrically acceptable? If all goods carry zero transaction costs or similar linear transaction costs there is no advantage in accepting money, a commonly traded good (that one doesn't want) in order to retrade it, instead of another that a fellow trader has in excess supply.

This leaves the theorist with the question: What structure of individual incentives or transaction costs results in a general equilibrium pattern of trade that follows Jevons' description?

It is well-known that the Arrow-Debreu model of Walrasian general equilibrium cannot account for money. Professor Hahn (1982) writes

> "The most serious challenge that the existence of money poses to the theorist is this: the best developed model of the economy cannot find room for it. The best developed model is, of course, the Arrow-Debreu version of a Walrasian general equilibrium. A first, and...difficult...task is to find an alternative construction without...sacrificing the clarity and logical coherence ... of Arrow-Debreu."

This paper pursues a simple example presenting a microeconomic foundation for the *double coincidence of wants* condition on barter trade, with a monetary exception. Precisely what Jevons foresaw. This is a model of monetary trade as the outcome of more elementary cost and utility conditions. The object is to develop a parsimonious example in keeping with the spirit of Walrasian general equilibrium theory that results in commodity money as a medium of exchange; money is to be a result of the model not an assumption. The double coincidence of wants condition — with monetary trade an exception to the condition — is to be the result of the general equilibrium pricing.

Absence of coincidence of wants means that the typical traded good will be traded more than once in moving from endowment to consumption. Barter trade successfully rearranging the allocation to an equilibrium will transact an endowment first at the trading post where it is supplied and again at a distinct post where it is demanded. Trading households each experience a set-up transaction cost on entry to each market. Hence monetary trade as an alternative (substituting retrade of money for the retrade of nonmonetary goods) can be undertaken without increasing total trading volume or transaction cost.

The fundamental first step is to create a general equilibrium where there is a well defined demand for a medium of exchange — a carrier of value between transactions. This is arranged by replacing the single budget constraint of the Arrow-Debreu model with the requirement that the typical household or firm pays for its purchases directly at each of many separate transactions at commodity-pairwise trading posts. This represents a formal distinction from the Arrow-Debreu model — there is not merely one budget constraint on an agent but many, one at each commodity-pairwise trading post where he trades.

The model posits a pure exchange economy with a trading post structure. For each possible pair of commodities, i and j, there is a separate trading post, denoted $\{i, j\}$ (or equivalently $\{j, i\}$), where the commodities are traded for one another. Transaction costs take a simple non-convex form: each household experiences a utility set-up cost on entering an additional trading post. Thus the household seeks to implement its desired purchases and sales while managing to restrict the number of trading posts where it is active. Transactions are a costly activity (in utility terms, at the household level), and thus they are priced.

The household faces a tradeoff. The minimum number of trading posts it can enter is reflected by the number of buying and selling pairs of goods it is interested in; if it has one good for sale and several for purchase, the minimum number of posts it can enter is equal to the number of desired purchases. But those markets may price the household's selling good at a discount. Conversely, if there is a common medium of exchange, commodity money, discounts may be smaller at the monetary trading posts but trading there will add to the number of trading posts the household enters with consequent personal cost.

A well-defined demand for media of exchange arises endogenously as an outcome of the market equilibrium. Money is not a social contrivance or an assumption. It is an outcome of the equilibrium. The price system in equilibrium creates and defines money. The use of commodity money is particularly evident when the structure of demands is characterized by an absence of double coincidence of wants, Jevons (1875). That is, we posit as a starting position endowments and tastes so that no two traders have complementary demands and supplies. That the only acceptable trades — with the exception of monetary trade — are those of complementary demands and supplies is a result of the equilibrium pricing. Media of exchange are characterized as the carrier of value between transactions(not fulfilling final demands themselves).

1.1 Structure of the Trading Post Model

In the trading post model, transactions take place at commodity pairwise trading posts (Shapley and Shubik (1977), Starr (2003, 2008), Walras (1874)) with budget constraints (you pay for what you get in commodity terms) enforced at each post. Prices are quoted as commodity rates of exchange. Market equilibrium occurs when prices at each trading post have adjusted so that all trading posts clear.

A barter equilibrium would consist of an outcome where most goods trade directly for one another, most trading posts becoming active. A monetary equilibrium occurs when most trading posts are inactive: trade concentrates on posts trading each good for the single common medium of exchange.

The paper considers two special cases: a small economy where the indivisibility of individual households has an impact and a large economy, where the indivisibility of individual households has no effect. In a small economy there will be a locally unique common medium of exchange — any good can serve as commodity money (there are multiple equilibria) — but in an equilibrium that choice will be unique. In a large economy, where the indivisibility of individual households has no effect, there may be several media of exchange in equilibrium.

2 Commodities and Trading Posts

Let there be N commodities, numbered 1,2,...N. They are traded in pairs — good i for good j — at specialized trading posts. The trading post for trade of good i versus good j (and vice versa) is designated $\{i, j\}$; trading post $\{i,j\}$ is the same trading post as $\{j, i\}$.

Thus there are $\frac{1}{2}N(N-1)$ possible trading posts.

3 Prices

Goods are traded directly for one another without distinguishing any single good as 'money'. Prices are then quoted as rates of exchange between goods. The present treatment does not distinguish between bid and ask prices. The price of a hamburger might be 5.0 chocolate bars. Note that the price of a chocolate bar then is the inverse of the price of a hamburger. That is, the price of a chocolate bar is 0.2 hamburger.

The price of i at $\{i,j\}$ is $q_i^{\{i,j\}}$. The price of i is in units of j. The price of j is in units of i. The price of j is the inverse of the price of i (and vice versa). That is, $(q_i^{\{i,j\}})^{-1} = q_j^{\{i,j\}}$ is the price of j in units of i.

4 Budget Constraints and Trading Opportunities

The budget constraint is simply that at each pairwise trading post, at prevailing prices, in each transaction, payment is given for goods received. This condition is embodied in constraint (T.ii) below. The multiplicity of budget constraints is the single most important distinguishing feature of the trading post model. It contrasts with the single lifetime budget constraint of the Arrow-Debreu model. Thus each household trading plan faces $\frac{1}{2}N(N-1)$ budget constraints.

5 Households

The distinctive features of the model are (i) transactions exchange pairs of goods, (ii) budget constraints are enforced at each transaction separately, generating a role for a carrier of value between transactions (a medium of exchange), (iii) transaction costs are incurred at the household level and are assumed to be nonconvex (displaying indivisibility). The transaction cost structure is that the household incurs a discrete cost with each trading post it transacts on, a cost that is increasing with the number of trading posts it uses.

For simplicity in the following example, let the population of households be identified with the N commodities. Each household, h will be designated as a type shown by one of $h = 1, 2, \cdots, N$. A household of type h then is endowed with $\mathcal{K}$ units of good h.

There are two special cases:

- A small economy with one household of each type $h = 1, 2, \cdots, N$. In the small economy, the indivisibility of each household causes quantity limits on the trade in individual trading posts and reinforces the implicit scale economy from the set-up character of transaction costs. This leads to local uniqueness of the commodity money in equilibrium.

- A large economy with the same large number of households of each type $h = 1, 2, \cdots, N$. The economy is large enough to overcome the impact from the implicit scale economy. Individual households still seek to economize on the number of trading posts they trade on, but there may be multiple media of exchange in equilibrium. The large numbers assure price-taking behavior and no non-price rationing in equilibrium at each trading post.

What is a "small" economy? An economy where markets are thin; in this setting it is a model where the scope for arbitrage at prevailing prices is significantly limited by the very small supplies actually available at a single trading opportunity (trading post). Moving from a theoretical model to interpretation for application, the notion would be that an economy on the scale of North America could probably support several independent currency systems, whereas an economy on the scale of La Jolla California would find that difficult. The ratio of the total volume of trade to the number of distinct commodities appears to be the approximate measure size.

Households formulate their trading plans deciding how much of each good to trade at each pairwise trading post. This leads to the rather messy notation:

$b_n^{h,\{i,j\}}$ = planned purchase of good n by household h at trading post $\{i,j\}$.

$s_n^{h,\{i,j\}}$ = planned sale of good n by household h at trading post $\{i,j\}$.

The notation $\oplus$ is defined in the following way. For any $n, j = 1, 2, \cdots, N$, $n \oplus j \equiv n + j$ if $n + j \leq N$, or $\equiv n + j - N$ if $n + j > N$. That is $n \oplus j$ is $n + j$ mod N.

In order to emphasize the absence of double coincidence of wants in the array of original endowments and tastes, we'll assume household $h°$ is endowed with good $h° = 1, 2, \cdots, N$ and prefers $h° \oplus 1, h° \oplus 2, h° \oplus 3$. Let $N \geq 10$. We can specify utility functions and market prices so that a market-clearing condition is fulfilled: for each good the amount demanded from the market equals the amount supplied to the market. But for any two households, there is no double coincidence of wants. Let $\ell > 0$. Then the typical household's utility function is

$$u^h(x^h) = \min[x^h_{h\oplus 1}, x^h_{h\oplus 2}, x^h_{h\oplus 3}] - \ell \cdot [\#\{b_i^{h\{i,j\}} \neq 0 \mid 1 \leq i, j \leq N\}]^\alpha \qquad \alpha > 1, \ell > 0$$

The concluding term in the expression for u^h reflects the notion that the household incurs a personal transaction cost for each trading post where the household conducts active trade. The cost starts at ℓ for the first post used, and increases per unit with each additional trading post used. Thus the household seeks to manage its trades to satisfy trading needs, represented as the first term on the RHS, while restricting the number of trading posts where it maintains activity.

Given $q_i^{\{i,j\}}, q_j^{\{i,j\}}$, for all $\{i,j\}$, household h then forms its buying and selling plans, in particular deciding which trading posts to use to execute his desired trades. Household h faces the following constraints on its transaction plans:

(T.i) $b_m^{h\{i,j\}} > 0$ only if $m = i, j$; $s_m^{h\{i,j\}} > 0$ only if $m = i, j$.

(T.ii) $b_i^{h(i,j\}} \leq q_j^{\{i,j\}} \cdot s_j^{h\{i,j\}}$, $b_j^{h\{i,j\}} \leq q_i^{\{i,j\}} \cdot s_i^{h\{i,j\}}$ for each $\{i,j\}$.

(T.iii) Nonegativity of all goods holdings at the conclusion of trade. Thus for each household h of type n, for all goods $m \neq n$, $\sum_{\{i,j\}}(b_m^{h\{i,j\}} - s_m^{h\{i,j\}}) \geq 0$, and for good n, $\sum_{\{i,j\}}(b_n^{h\{i,j\}} - s_n^{h\{i,j\}}) + \mathcal{K} \geq 0$.

Note that condition (T.ii) defines a budget balance requirement at the transaction level, implying the decentralized character of trade. Since the budget constraint applies to each pairwise transaction separately, there may be a demand for a carrier of value to move purchasing power between distinct transactions. h faces the array of prices $q_i^{\{i,j\}}, q_j^{\{i,j\}}$ and chooses $s_m^{h\{i,j\}}$ and $b_m^{h\{i,j\}}$, $m = i, j$, to maximize $u^h(x^h)$ subject to (T.i), (T.ii), (T.iii). That is, h chooses which pairwise markets to transact in and a transaction plan to optimize utility, subject to a multiplicity of pairwise budget constraints. A **competitive equilibrium** consists of $q_i^{o\{i,j\}}$, $q_j^{o\{i,j\}}$, $1 \leq i, j \leq N$, so that :

- For each household h, there is a utility optimizing plan $b_n^{oh\{i,j\}}$, $s_n^{oh\{i,j\}}$, (subject to T.i, T.ii , T.iii) so that for each $\{i,j\}$, each n,

- $\sum_h b_i^{oh\{i,j\}} \leq \sum_h s_i^{oh\{i,j\}}$, all $i \neq j$, with $q_i^{o\{i,j\}} = 0$ for i so that the strict inequality holds.

An equilibrium is said to be **monetary** with a commodity money, μ, if all transactions are at trading posts including μ and μ is the only good that a household will both buy and sell.

6 A Monetary Equilibrium

We seek sufficient conditions in an example so that there is an equilibrium pattern of trade where all trade goes through a common medium of exchange, a commodity money. The strategy is to consider three possible patterns of trade by households: barter, monetary trade, arbitrage on the barter markets. Barter trade by the household consists of trading on three trading posts: endowed good versus the three desired goods. Monetary trade consists of trading on four trading posts: endowed good versus commodity money, commodity money versus three desired goods. Arbitrage consists of trade on five trading posts: endowed good versus a second good, second good versus commodity money, commodity money versus three desired goods. In a small economy, quantity constraints may mean that arbitrage requires trade at six trading posts. We then find trading post break-even prices so that barter and monetary trade are equally successful and so that monetary and arbitrage trade are equally successful. Based on the break-even prices, we can find pricing so that monetary trade is the most rewarding strategy.

In the case where there is a common medium of exchange, commodity money, start by assuming that it trades one-for-one with each of the other goods, fixing money's price at unity. Since all goods enter symmetrically in agents' utility functions, the example below will assume symmetric pricing. Goods 2, 3, 4 are desired by type 1 households. 3, 4, and 5 are desired by type 2 households. ... Goods 1, 2, 3 are desired by type N households. Hence we assume $q_i^{\{i,i\oplus 1\}} = q_i^{\{i,i\oplus 2\}} = q_i^{\{i,i\oplus 3\}}$ for $1 \leq i \leq N$ (with the exception of the case where $i, i \oplus 1, i \oplus 2$, or $i \oplus 3$ is the commodity money and hence the price is unity).

At trading posts $\{i, i \oplus 1\}, \{i, i \oplus\}, \{i, i \oplus 3\}$, good i is in supply and $i \oplus 1, i \oplus 2, i \oplus 3$, are in demand. Hence i trades at a discount; $i \oplus 1, i \oplus 2$, and $i \oplus 3$ trade at a premium.

6.1 Better than Break-Even Prices

6.1.1 Pricing where monetary trade is superior to barter

Denote the price of the typical non-monetary good owned by household of type i in exchange for a desired good under barter, $q_i^{\{i,i\oplus 1\}}$, by q. By symmetry we take this value to be the same across all non-monetary goods. We'd like to figure out the value of q so that a type i household is better satisfied trading in monetary fashion. In the following expression, the left hand side is the utility of the typical household under barter trade; the right hand side is the utility of a similar household under monetary trade. The inequality is intended to characterize q° so that monetary trade is preferable to barter.

$$q\frac{\mathcal{K}}{3} - 3^\alpha \ell < \frac{\mathcal{K}}{3} - 4^\alpha \ell$$

Solving for the barter price q° where monetary trade is superior we get that

$$q^\circ < 1 - \frac{3}{\mathcal{K}}(4^\alpha - 3^\alpha)\ell$$

Thus, when barter is sufficiently costly, monetary trade will be superior. Low values of $q_i^{\{i,i\oplus 1\}}$, the barter value of good i, drive trade to using money. How low can q go? If q gets too low, the price will induce arbitrage buying. That limit is investigated next.

6.1.2 Pricing where monetary trade is superior to arbitrage in a large economy

In the following expression, the left hand side is the utility of the typical household under monetary trade; the right-hand side is the utility of a similar household performing the following arbitrage: good i for j, j for money, money for $i \oplus 1, i \oplus 2, i \oplus 3$. The inequality is intended to characterize $q^\dagger$, the floor on prices set by the possibility of arbitrage.

$$\frac{\mathcal{K}}{3} - 4^\alpha \ell > \frac{\mathcal{K}}{3q} - 5^\alpha \ell$$

Solving for the lower bound on the barter price q, $q^\dagger$, where monetary trade is superior, we find

$$q > q^\dagger = [1 + (\frac{3}{\mathcal{K}}(5^\alpha - 4^\alpha)\ell)]^{-1}$$

6.1.3 Arbitrage-free pricing in a small economy

In a small economy matching buyers and sellers is particularly difficult because household quantity limits on the size of desired trades at any single trading post are a binding constraint. Kiyotaki and Wright (1989) agree with Jevons (1875) in emphasizing the importance of a successful match to implement barter and conversely the monetary alternative.

The small economy has a unique household h of type n. Then when h considers barter trade at trading post $\{n, n \oplus 1\}$, h will supply only $\frac{\mathcal{K}}{3}$ of n. An arbitrageur endowed with $n \oplus 1$ considering buying n on $\{n, n \oplus 1\}$ recognizes that he must trade on six different trading posts: $\{n, n \oplus 1\}$ for his arbitrage, $\{money, n \oplus 1\}$ to sell the remainder of his endowment, $\{money, n\}$ to resell the arbitrage purchase, $\{money, n \oplus 2\}, \{money, n \oplus 3\}, \{money, n \oplus 4\}$ to acquire his desired consumptions. Thus the discount on n at $\{n, n \oplus 1\}$ needs to be sufficiently large to compensate for the additional transaction costs. The quantity x of the abritrageur's endowment of $\mathcal{K}$ that will be utility maximizing for him expend at price q is characterized by $\frac{1}{q}x = \frac{1}{2}(\mathcal{K} - x)$. This solves out as $x = \frac{q\mathcal{K}}{2+q}$.

This leads to characterizing arbitrage as unprofitable by

$$\frac{\mathcal{K}}{3} - 4^{\alpha}\ell > \frac{1}{3}[\frac{1}{q}x + (\mathcal{K} - x)] - 6^{\alpha}\ell = \frac{1}{3}[\frac{1}{q}\frac{q\mathcal{K}}{2+q} + (\mathcal{K} - \frac{q\mathcal{K}}{2+q})] - 6^{\alpha}\ell$$

Simplifying this expression to characterize sufficient conditions on q so that arbitrage is unprofitable and monetary trade is superior we have

$$\frac{3(6^{\alpha} - 4^{\alpha})\ell}{\mathcal{K}} > \frac{1-q}{2+q}$$

This expression does not result in a precise value of $q^{\dagger}$, a lower bound on q consistent with prevalence of monetary trade. The RHS is bounded above by $\frac{1}{2}$ and the LHS is unbounded. Thus for α and ℓ sufficiently large, monetary trade is overwhelmingly superior to arbitrage. The implication is that monetary trade's superiority is particularly intense in a small economy. In addition, note that in the small economy, it is essential that the monetary instrument be unique in order to match the volume of buy and sell orders for each good on the monetary trading posts. In the large economy, on the contrary, many instruments may act as media of exchange. This suggests that Menger (1892)'s description is particularly appropriate in a small economy,

> why...is...economic man ...ready to accept a certain kind of commodity, *even if he does not need it*, ... in exchange for all the goods he has brought to market[?]
>
> Men ... exchange goods ... for other goods ... more saleable....[which] become generally acceptable media of exchange [emphasis in original].

6.1.4 Sustainable pricing in a monetary equilibrium

Thus monetary trade will be sustained where $q^\circ > q_i^{\{i,i\oplus1\}} > q^\dagger$. This interval is nonempty in a large economy when

$$1 > 1 - \frac{3}{\mathcal{K}}(4^\alpha - 3^\alpha)\ell > 0, \qquad (*) \text{ and}$$

$$1 - \frac{3}{\mathcal{K}}(4^\alpha - 3^\alpha)\ell > [1 + (\frac{3}{\mathcal{K}}(5^\alpha - 4^\alpha)\ell)]^{-1}$$

or equivalently when

$$[1 - \frac{3}{\mathcal{K}}(4^\alpha - 3^\alpha)\ell][1 + (\frac{3}{\mathcal{K}}(5^\alpha - 4^\alpha)\ell)] > 1 \qquad (**)$$

(*) says that the transaction costs of monetization are not in themselves overwhelming. The inequality (**) will generally be true for $\alpha > 1$ and $\ell > 0$, such that (*) is true .

In a small economy, the less precise sufficient condition is (*) and

$$\frac{3(6^\alpha - 4^\alpha)\ell}{\mathcal{K}} > \frac{1}{2} \qquad (***)$$

which will be fulfilled for α, ℓ sufficiently large.

6.2 Monetary Equilibrium Pricing

Let $q^\circ > q^* > q^\dagger$. Table 1 presents the equilibrium prices for a monetary equilibrium. Good n^* is the commodity money. The choice of good n^* is arbitrary, since all goods in this example are symmetric, but it is treated asymmetrically as the common medium of exchange. $q_i^{\{i,n^*\}} = 1$ and $q_{n^*}^{\{n^*,j\}} = 1$. The typical price, $q_i^{\{i,j\}}$, is the price for good i at trading post {i, j}. For $i, i\oplus1, i\oplus2, i\oplus3 \neq n^*$, we have $q^\dagger < q^* = q_i^{\{i,i\oplus1\}} < q^\circ$, $q^\dagger < q^* = q_i^{\{i,i\oplus2\}} < q^\circ$, and $q^\dagger < q^* = q_i^{\{i,i\oplus3\}} < q^\circ$. Conversely, $q_{i\oplus1}^{\{i,i\oplus1\}} = [q_i^{\{i,i\oplus1\}}]^{-1}$. At these prices all trade proceeds through the trading posts trading n^*.

[**Table 1 goes here**]

The monetary equilibrium in Table 1 establishes the *double coincidence of wants* condition on the pattern of trade as an outcome of the general equilibrium. At prevailing prices, good i is priced at a discount at trading posts $\{i, i\oplus1\}, \{i, i\oplus2\}, \{i, i\oplus3\}$ and at a premium at posts $\{i,(i-4)\oplus1\}, \{i,(i-4)\oplus2\}, \{i,(i-4)\oplus3\}$. Goods trade only where they are wanted. The pattern of trade is an outcome, not an assumption, of the example, reflecting the structure of transaction cost.

7 Media of Exchange

Thus the trading post equilibrium establishes a well-defined demand for media of exchange as an outcome of the market equilibrium. Media of exchange (commodity monies) are characterized as goods flows acting as the carrier of value between transactions (not fulfilling final demands themselves).

8 Conclusion

The price system is informative not only about scarcity, desirability, and productivity. It also prices liquidity. n^* is endogenously determined as the most liquid good, a quality reflected in its pricing. The multiplicity of budget constraints creates the demand for liquidity. The trading post model endogenously generates a designation and flow of commodity money. The double coincidence of wants condition is an outcome of market equilibrium. Where non-monetary goods are offered in barter trade, their prices are deeply discounted.

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Table 1: **Monetary Equilibrium Trading Post Prices**

selling:		**1**	**2**	**3**	$\cdots$	n^*	$\cdots$	**N-1**	**N**
buying:	**1**	X	$q_2^{\{1,2\}} = [q^*]^{-1}$	$q_3^{\{1,3\}} = [q^*]^{-1}$	$\cdots$	1	$\cdots$	$q_{N-1}^{\{1,N-1\}} = q^*$	$q_N^{\{1,N\}} = q^*$
	2	$q_1^{\{2,1\}} = q^*$	X	$q_3^{\{2,3\}} = [q^*]^{-1}$	$\cdots$	1	$\cdots$	$q_{N-1}^{\{2,N-1\}} = q^*$	$q_N^{\{2,N\}} = q^*$
	3	$q_1^{\{3,1\}} = q^*$	$q_2^{\{3,2\}} = q^*$	X	$\cdots$	1	$\cdots$	$q_{N-1}^{\{3,N-1\}}$	$q_N^{\{3,N\}} = q^*$
	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\ddots$	1	$\vdots$	$\vdots$	$\vdots$
	n^*	1	1	1	1	X	1	1	1
	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	1	$\ddots$	$\vdots$	$\vdots$
	N-1	$q_1^{\{N-1,1\}} = [q^*]^{-1}$	$q_2^{\{N-1,2\}} = [q^*]^{-1}$	$q_3^{\{N-1,3\}}$	$\cdot$	1	$\cdot$	X	$q_N^{\{N-1,N\}} = [q^*]^{-1}$
	N	$q_1^{\{N,1\}} = [q^*]^{-1}$	$q_2^{\{N,2\}} = [q^*]^{-1}$	$q_3^{\{N,3\}} = [q^*]^{-1}$	$\cdots$	1	$\cdots$	$q_{N-1}^{\{N,N-1\}} = q^*$	X