Economic Organization with Limited Communication

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1. INTRODUCTION

Economic agents are naturally separated in time and space. In an economy at large agents reside typically in various locations, work at alternative distinct locations, and meet to make exchanges or deals at distinct locations still. And even within a more narrowly defined group, such as those constituting a firm, not all agents are typically in constant touch with one another. Further, economic agents naturally experience private information, realizations of endowment or technology shocks seen only by individuals directly involved. Still, despite this separation and private information, groups of agents, such as those constituting a firm, or even economy-wide groups with more disparate interests, do attempt to find mutually beneficial, multilateral arrangements. The purpose of this paper is to examine the types of multilateral arrangements which are viable and beneficial for such groups and to establish that such arrangements depend very much on the ability of agents to communicate with one another.

In its method this paper follows the literature on contract theory and mechanism design of Harris and Townsend (1981), Myerson (1979), and Townsend (1982), for example, stressing private information and incentives. The idea, essentially, is to specify the endowments and preferences of the agents and the production technology available to them; to be precise about the information structure; and, here, to be precise about the location itineraries of the agents and the communication technology. Then, rather than imposing a fixed contract form or resource allocation scheme, one considers a broad class of arrangements and determines the constraints implied by private information, and, here, by spatial separation and limited communication. One then goes on to determine Pareto optimal arrangements, by maximizing weighted averages of the utilities of the agents subject to the obvious resource constraints and these derived incentive compatibility constraints. Finally, by varying the technology of communication, one induces variations in the derived incentive constraints, and in this way, in the context of the programming problem, one can capture formally the idea that communication systems matter and that particular systems may be more or less limited.

An attempt is made also in this paper to match the communication systems of the theory with communication systems in actual use in historical, primitive, or contemporary structures. In particular, an attempt is made to interpret observed financial structures as instances of the communication systems described in the theory. Of course this matching effort is somewhat heroic, if not controversial, since not all the key assumptions of the theory match up well with reality. In particular, the theory assumes unlimited commitment, no default, and an ability to monitor communication and exchange quite closely, whereas in practice, limited commitment, default, and highly imperfect monitoring are important, especially as regards the determination of financial structure.[1] Still, an attempt is made here to match the location or person-specific assignment systems of the theory with central exchanges, registrars of deeds, and banks or intermediaries; to match the portable object systems of the theory with various currency arrangements; and to match the written message systems of the theory with the use of financial instruments and commercial paper.

It is worth while stressing at this point that the theory of this paper takes as exogenous various features which are endogenous in practice and which further theory might attempt to explain. In particular, by assuming unlimited commitment and no default and by varying the communication technology exogenously one does not face the question of what determines the extent or size of the group using a particular communication technology at a point in time or why groups or technology change over time. It is hoped, however, that by better understanding the role of pre-

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[1]We know, for example, that limited commitment is a key element in recent theories which attempt to explain valued currency, as in the spatial models of Townsend (1980) and various overlapping generation setups. Also, this idea seems to match up well with reality. On the other hand, this paper hopes to contribute to our understanding of currency by assuming full commitment and examining whether there is any role left for currency to play.

specified communication systems for pre-specified groups we are better posed to begin to answer some of these fundamental, difficult questions.

Finally, an attempt should be made in this introduction to relate this paper to existing literature. Closest in many ways is the paper of Gale (1980) in which reference is made to paper assets as accounting devices in a world with a continuum of agents and a limited social planner. Gale's focus is on conditions sufficient to ensure that a sequential competitive equilibrium with valued money achieves a full-information Pareto optimum. Here the focus is on a private-information Pareto optimum in worlds with spatial separation and explicit, limited communication, in which various kinds of financial assets are associated with various kinds of communication systems. A second literature to which the proposed research is related is the literature on limited communication in resource allocation mechanisms, of Hurwicz (1972), Mount and Reiter (1974), and others. Here financial instruments of one kind or another are literally the messages which agents send to one another. Of course, the idea that money reflects some "decentralization" in the exchange process appears frequently in the literature, but one should note here, in particular, the work of Brunner and Meltzer (1971) in which money emerges in a world with an uneven distribution of information, essentially by reducing the costs of acquiring information and of constructing transaction chains, the work of Radner (1968) on the emergence of money in competitive market models in which "computational complexity" somehow limits trades, and the work of Ostroy (1973) and Ostroy-Star (1974), in which trading rules are said to be decentralized to the extent that they do not depend on past histories. Finally, this paper is related to the work of Ross (1977) and the idea that financial decisions act as signals in worlds with private information.

Briefly, then, the paper proceeds as follows. Section 2 illustrates the contract-theoretic approach, that is, how to determine an optimal resource allocation mechanism and an optimal allocation of resources for a 2-agent, one-period example economy in which quantities such as endowments of one of the agents, are private information.[2] This is done, essentially, by extending what is now known as the 'revelation-principle' to the environment of the example. Extensions to the more general environment of the paper are then fairly obvious. A key aspect of these extensions is the use of a double transfer, tax-subsidy scheme. Section 3 gives an example which illustrates the use of this scheme and which constitutes a base for analysis in the rest of the paper. Section 4 describes an extended, 4-agent, two-period example economy in which there is a restriction to a location-specific, oral assignment system. An example illustrates how damning such a restriction can be if there is spatial movement. Indeed, Section 5 shows how costs might be incurred so as to allow intertemporal links and a gain to more enduring relationships. Section 6 shows in turn how a restriction to location-specific assignment systems can be mitigated if there are repeated intermittent meetings among the agents. In effect, this section envisions a role for a person-specific assignment system, that is, a role for a go-between or intermediary. Section 7 goes on to interpret, relative to the theory, actual location- or person-specific assignment systems in use in various places and dates.

Section 8 shows how portable record-keeping devices such as concealable tokens can further overcome transactions difficulties. Section 9 shows that bona fide commodity tokens can play a similar, albeit more limited role. Section 10 in turn envisions a role for multiple, differentiated tokens. Section 11 then interprets, relative to the theory, various portable object systems in use at various places and dates. Written message systems are considered in Section 12, systems which are complete relative to the requirement that messages be transported with people. These systems are interpreted in Section 13. Finally, Section 14 offers a brief comment on telecommunications systems, both in theory and in practice.

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[2] It might be noted that much of the literature on resource allocation mechanisms ignores privately observed endowments. Important exceptions are Postlewaite (1974), Hurwicz, Maskin and Postlewaite (1980) and also Pithyachariyakul (1981).

2. OPTIMAL SOCIAL ARRANGEMENTS IN A CLOSED COMMUNITY WITH UNOBSERVED QUANTITIES

To begin, we shall illustrate the contract theoretic arguments of this paper and consider how to determine an optimal social arrangement in a closed community, one in which all agents are together at a single location, and in which, consistent with Harris and Townsend (1981), Myerson (1979), and Townsend (1982) there is essentially unlimited communication. Here, however, in anticipation of what is to follow in later sections, where concealed portable objects are viewed as privately-observed beginning-of-period state variables, we shall focus on endowments as privately-observed variables and ask whether such quantity information can be exploited.

Thus, consider a simple economy consisting of just two agents, a and b, who are paired with one another at two dates, a planning period t=0, and a consumption period t=1 (obviously the common trading location need not be named and its name can be deleted from the notation). The economy is subject to shocks θ at t=1, observed by agent a alone. Indeed, suppose the endowment of agent a at t=1 is a non-negative vector, denoted $\theta^a_1 = \theta$ for simplicity, and is random, taking on one of two possible values, θ' or θ'' at the beginning of date t=1. Again the realizations of θ are known only to agent a. Let $\Theta = \{\theta', \theta''\}$. The endowment of agent b at t=1 is some constant, say $\theta^b_1 = W$ and hence known by everyone. The preferences of agent a over consumption at date t=1 in event shock θ is realized are represented by a state- dependent utility function $U^a(c^a, \theta)$ which for each θ is strictly increasing, strictly concave, and displays decreasing absolute risk aversion. The preferences of agent b are represented by a utility function $U^b(c^b)$ which is strictly increasing and weakly concave. In the planning period the two agents sit down with one another to agree upon some resource allocation scheme. We shall suppose that they have under consideration a fairly broad class.

Suppose in particular that agents have under consideration a social arrangement or resource allocation mechanism of the following type. At date t=1 after θ is known to agent a, agent a can send a message m to agent b, or to some center. In general, the set of all possible messages $\mathcal{M}$ can be quite unrestricted in nature, but for simplicity here it is supposed to be a subset of a finite dimensional Euclidean space. Once the message space $\mathcal{M}$ is specified, however, it cannot be altered. Upon receipt of a message $m \in \mathcal{M}$ it is understood that two rounds of transfers are to take place. The first round is "tax" $\tau=(\tau^a,\tau^b)$, where τ^i is a tax on agent i, i=a,b. This tax may be imposed in a random way, in accord with some probability measure $p^\tau(m)$, conditional on the message m. More formally, given the endowment θ, the space of feasible taxes τ is defined by $0 \leq \tau^a \leq \theta$, $0 \leq \tau^b \leq W$. Let $T(\theta)$ denote the space of probability measures over such feasible taxes, and suppose that probability measures $p^\tau(m)$, $m \in \mathcal{M}$, lie in $\bigcup T(\theta)$ and are thus feasible for *some* endowment θ. The second round transfer is a "subsidy" $s=(s^a,s^b)$ where s^i is a subsidy to agent i, i=a,b. The subsidy is imposed in accord with some probability measure $p^s(m,\tau)$, conditional on the initial message m and the first round tax τ. More formally, given the tax τ, the space of feasible subsidies is defined by $s^a \geq 0$, $s^b \geq 0$, $s^a+s^b \leq \tau^a+\tau^b$. Let $S(\tau)$ denote the space of probability measures over such feasible subsidies, and suppose that the measures $p^s(m,\tau)$, $m \in \mathcal{M}$, lie in $S(\tau)$. Note that each measure $p^s(m,\tau)$ is restricted to be a well-defined conditional probability measure. Finally, of course, once specified, the measures $p^\tau(m)$ and $p^s(m, \tau)$, $m \in \mathcal{M}$, completely determine all possible transfers between the agents. Thus it is supposed that there is some technology which precludes reneging or default.

Confronted with a resource allocation mechanism, that is, a message space $\mathcal{M}$ and measures $p^\tau(m)$ and $p^s(m,\tau)$, and given the shock $\theta \in \Theta$, agent a determines all feasible messages which he might send, all messages under which he can pay any tax which might be imposed, that is, such that $p^\tau(m) \in T(\theta)$. The idea here is that having announced message m the agent must put up front, on the table as it were, in open view, the amount of the consumption good required for any realization of the lottery $p^\tau(m)$. It then chooses the best such message. Thus agent a solves

$$\underset{m \in \mathcal{M}}{\text{Max}} \iint U^a[\theta - \tau^a + s^a, \theta]\, p^s(m, \tau, ds)\; p^\tau(m, d\tau). \tag{1}$$

The best such message, assuming existence, is denoted $m*(\theta)$[3].

By construction of $m*(\theta')$, say,

$$\iint U^a[\theta' - \tau^a + s^a, \theta']\, p^s(m*(\theta'), \tau, ds)\; p^\tau(m*(\theta'), d\tau)$$

$$\geq \iint U^a[\theta' - \tau^a + s^a, \theta']\, p^s(\bar{m}, \tau, ds)\; p^\tau(\bar{m}, d\tau) \tag{2}$$

for all messages $\bar{m}$ which are feasible given θ', that is, such that $p^\tau(\bar{m})$ is an element of $T(\theta')$. In particular, consider the probability measure chosen in some counterfactual situation, say $p^\tau[m*(\theta'')]$, when $\theta = \theta''$. Then either that measure is not feasible given $\theta = \theta'$

$$p^\tau[m*(\theta'')] \notin T(\theta') \tag{3}$$

or it is weakly dominated given $\theta = \theta'$,

$$\iint U^a[\theta' - \tau^a + s^a, \theta']\, p^s[m*(\theta'), \tau, ds]\, p^\tau[m*(\theta'), d\tau] \geq$$

$$\iint U^a[\theta' - \tau^a + s^a, \theta']\, p^s[m*(\theta''), \tau, ds]\, p^\tau[m*(\theta''), d\tau]. \tag{4}$$

It now becomes apparent that we might well have restricted ourselves to simpler resource allocation schemes, ones which allow agent a to make a direct announcement θ, that is, with message space $\mathcal{M} = \{\theta', \theta''\}$, and in which such announcements effect random taxes and (conditional) subsidies $\pi^\tau(\theta)$, and $\pi^s(\theta, \tau)$, respectively. Further, the random taxes and subsidies π can be constructed in such a

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[3] More generally, we might have allowed agent a to adopt a random strategy $\delta(\theta)$, a probability measure over the space of possible messages $\mathcal{M}$. Clearly, though, agent a would only randomize over messages among which he is indifferent, so a degenerate random strategy would always be maximizing. The notation in the text assumes some selection rule when the best choice is not unique.

way that agent a will make announcements truthfully. That is, given some arbitrary initial resource allocation scheme with message space M, random transfers p, and maximizing strategies $m^*(\theta)$, let

$$\pi^T(\theta) = p^T[m^*(\theta)]$$
$$\pi^S(\theta,\tau) = p^S[m^*(\theta),\tau]. \tag{5}$$

Then, by equations (3)-(4), given the shock, say $\theta=\theta'$, either the announcement $\theta=\theta''$ is not feasible, that is,

$$\pi^T(\theta'')\notin T(\theta') \tag{6}$$

or such an announcement is weakly dominated by truth-telling, announcing $\theta=\theta'$,

$$\iint U^a[\theta'-\tau^a+s^a,\theta']\pi^S[\theta',\tau,ds]\pi^T[\theta',d\tau]$$
$$\geq \iint U^a[\theta'-\tau^a+s^a,\theta']\pi^S[\theta'',\tau,ds]\pi^T[\theta'',d\tau]. \tag{7}$$

Thus truth-telling when $\theta=\theta'$ is maximizing even if lying is feasible. Of course a similar condition holds when $\theta=\theta''$.

Any of these simpler, so-called (truth-telling) direct revelation schemes is entirely characterized by the tax-subsidy probability measures $\pi^T(\theta)$, $\pi^S(\theta,\tau)$, $\theta\in\Theta$. In effect these probability measures π form a contract between agents a and b in which agent a has several individually-effected options or contingencies, options which can be claimed at agent a's discretion without verification.[4] Again, these probability measures must satisfy equations (6), (7) and their analogues for $\theta=\theta''$. Thus it is that the determination of an optimal social arrangement is reduced to the problem of choosing the contract π in a Pareto optimal fashion. In short, we are reduced to a programming problem.

[4]For more on this interpretation, see Prescott and Townsend (1984a, 1984b).

Programming Problem 1:

Maximize

$$\omega^a \Sigma_\theta \text{ Prob } (\theta) \iint U^a[\theta - \tau^a + s^a, \theta]\pi^s[\theta,\tau,ds]\pi^\tau[\theta,d\tau]$$

$$+ \omega^b \Sigma_\theta \text{ Prob } (\theta) \iint U^b[W - \tau^b + s^b]\pi^s[\theta,\tau,ds]\pi^\tau[\theta,d\tau]. \tag{8}$$

by choice of measures $\pi^\tau(\bullet)$ and $\pi^s(\bullet)$, subject to equations (6) and (7) and their analogue $\theta = \theta^n$, where ω^a and ω^b are fixed weights between zero and unity, summing to unity. Finally, if we wish to ensure that no agent be made worse off in this optimal social arrangement than he would be without trading, that is, by consuming his endowment, we may easily append onto Problem I certain individual rationality constraints which ensure that outcome.

That the determination of an optimal social arrangement can be reduced to the problem of finding a solution to some programming problem is quite general, subject only to a few caveats. That is, we might have allowed agent a to suffer from a finite number of possible shocks $\theta \epsilon \Theta$, Θ finite, or agent b to suffer random, privately-observed shocks as well. Or we might have allowed both agents to live an arbitrary (finite) number of periods. Indeed, consistent with the general structure, we might have layered on a finite number of agents with arbitrary period-by-period pairings. Further, as we shall see momentarily, we might have allowed explicit restrictions on communication; for example, we might have supposed that when agents are paired with one another, they know only the history of their own mutual communications. Less limited but still imperfect communication of past messages will also be considered. But none of these extensions alters the fact that the determination of an optimal social arrangement or resources or an optimal contract reduces to the problem of finding a solution to a well-defined programming problem.[5]

One might also note that there is supposed to be no reneging, default, or ex post collusion in the present set-up. That is, all agents, abide by the rules of the resource allocation scheme, the $\Pi(\cdot)$, as if there were a perfect, costless commitment technology, one which limits the set of possible transfers and set of possible messages and which links these two together as agreed upon initially. For specificity, one might conjure up an image of conveyor belts and preset microphones with no options to walk away. Of course in practice commitment devices are not so fantastic, and it might be supposed that agents do seek to renege or collude whenever possible. In this way, then, the existence and nature of commitment and monitoring technologies takes on considerable importance. Still, in any more elaborate theory, one might hope to maintain the distinction emphasized in this paper between known reneging on preexisting agreements and the prescribing of messages or actions contingent on private information, something which is inherently unenforceable.

3. AN EXAMPLE DISPLAYING THE DOUBLE TRANSFER SYSTEM

Having issued all these disclaimers, we may now return to the simple 2-agent structure described earlier, assume there is only one good, and proceed to characterize explicitly a Pareto optimal social arrangement. This will serve to illustrate how the two-round, tax-subsidy system can be used to overcome apparent incentive problems. The example will also serve to establish that the constructs developed thus far are not vacuous.

To proceed, suppose the shocks realizations of agent a are observed by agent

[5] Of course there always remains open the question of whether the class of resource allocation schemes considered was without loss of generality or, better put, utility. For example, one might have considered sequential within-period mechanisms as in Harris and Townsend (1977), (1981), or distribution functions which are less restricted, say allowing first-round taxes to be negative and/or second-round subsidies to be negative. It is claimed that neither of these less restrictive specifications would really broaden the class of resource allocation mechanisms under consideration, but there may well be some which do indeed broaden the class. One might conjecture, of course, that the spirit of the results of this paper would not be altered in such an event, but that must be left as an open question.

b (though in the end we will be assuming that they are observed by agent a alone). With publicly observed shocks, we may then proceed to characterize an optimal risk-sharing arrangement with the usual state-space analysis. That is, as Figure 1 illustrates, the economy under consideration is associated with a standard Edgeworth box diagram. The endowment of agent a is high in state one, say $\theta=\theta''$,

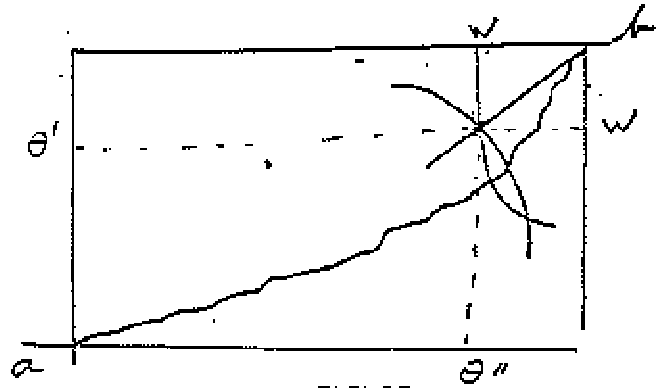

FIGURE 1

and low in state two, say $\theta=\theta'$, with the endowment of agent b a constant and thus on the 45° line from the origin of agent b. From the point of view of t=0, prior to shock realizations, the two agents attempt to settle on an optimal allocation of state-contingent consumption claims, an allocation on the contract curve subject to individual rationality.

There are two cases to be considered. For the first, suppose utility functions are such that the contract curve in the lens-shaped, Pareto improving trade region lies entirely southeast of the endowment point e, as illustrated in Figure 1. Then for a consumption allocation c on that portion of the contract curve, agent a is to *receive* the consumption good when his endowment is high, at $\theta=\theta''$, and is to surrender the consumption good when his endowment is low $\theta=\theta'$. With public information on shocks, the final consumption allocation c is attainable. Of course with shock realizations of agent a private to himself, agent a always would claim the endowment is high, effecting a positive transfer of the consumption good. But it is now argued that this incentive problem can be removed by two-round, tax-subsidy systems. In particular, if agent a claims his endowment is low, $\theta=\theta'$, let him pay a tax which gives him the consumption allocation c_2; let the subsidy associated with the claim $\theta=\theta'$ be zero. If agent a claims a high endowment, $\theta=\theta''$, let him pay a tax which exceeds the low endowment value, $\theta=\theta'$, and then receive a subsidy which gives him the consumption allocation c_1. In this way, agent a will claim a high endowment when the endowment actually is high, but will be unable to claim a high endowment when the endowment actually is low, since he must pay the first-round tax. In summary, then, in this rather special setting, agents can achieve a full-information optimal allocation, even though there is private information (this result is special; full information optimal allocations generally will be unattainable).

A second case is also of some interest. Suppose the lens-shaped region in Figure 1 were to lie entirely northwest of the endowment, as would be the case, for example, if there were no shocks to preferences, agent a were risk averse, and agent b were risk neutral. Indeed, hereafter, we shall drop the shocks from agent a's utility function altogether. Then any trade which improves upon autarky has agent a receiving the consumption good when his endowment is low. Of course the incentive problem is that agent a would always want to claim the endowment is low. Suppose moreover, that we contemplate a first-round tax. But any tax which can be paid when the endowment is low, can be paid also when the endowment is high, thus leaving us with the same incentive problem. Finally, suppose we imagine there can be mutually beneficial exchange with lotteries. The mean or average consumption allocation must lie in the lens-shaped region, as randomness and risk aversion can only make agents worse off than as if receiving the mean consumption itself. This implies agent a has an expected net receipt if $\theta=\theta'$ is realized and is claimed and an expected net payment if $\theta=\theta''$ is realized and is claimed. Again, randomness can only enhance utility loss and reduce utility gain. But under our hypothesis, utility is increased overall so we must be assuming a utility gain when $\theta=\theta'$ is realized and is claimed. Thus agent a has an incentive to claim $\theta=\theta'$ when indeed $\theta=\theta'$ is realized. But then agent a would also experience a utility gain when $\theta=\theta'$ is claimed even when $\theta=\theta''$

is realized — his expected net receipt occurs when $\theta=\theta'$ is claimed, and with a concave utility function, decreasing absolute risk aversion and $\theta''>\theta'$, the utility loss associated with the randomness in that net receipt is even less than if $\theta=\theta'$ were realized. This contradicts the supposition, and so lotteries do not alleviate the incentive problem. In short, there can be no mutually beneficial trade in this case, and the optimal resource allocation mechanism is associated with autarky (again, this result is special; the incentive problems of private information are generally not so damning).

4. THE LIMITATIONS OF LOCATION-SPECIFIC ASSIGNMENTS SYSTEMS IN SPATIAL SETTINGS

We shall now introduce spatial separation into our closed economy and consider first the most primitive of communication systems, namely, location-specific, oral assignment systems. Thus, consider an economy with 4 agents labelled a, a', b, b' and two trading locations, labeled 1 and 2. Each agent i lives two periods (in addition to the t=0 planning date) and, for simplicity, faces an exogenously given itinerary or sequence of pairings with other agents as described in Table 1.

location	1	2
date 1	(a,b)	(a',b')
2	(a,b')	(a',b)

TABLE 1

Thus agents a and a' have permanent residence in locations 1 and 2 respectively. Agents b and b' are initially paired with a and a' respectively, but switch locations in the second period. Each agent i has a within-period utility function $U^i(\bullet)$ over contemporaneous consumption vectors and discounts the future by parameter β, $0<\beta\leq 1$.

Now, suppose for simplicity that all agents somehow manage to get together with one another at date t=0, at some (central) location, to set up an optimal social arrangement, a two-location, oral assignment, record-keeping system. That is, agents agree at t=0 on the set of possible messages which can be sent between the two agents of each agent pairing at each date and location. For example, agents a and a' may each agree to report on privately-observed incomes. Further, agents agree on the tax-subsidy rules in place at each date and location, the set of tax and subsidy probability measures which are to be effected by these individual messages or claims. Finally, as before, there is assumed to be no reneging or default on these agreements, as if there were some fantastic perfect commitment technology. But the communication is imagined here to be entirely oral, and limited to the two locations, and so for the example economy described above, the allocation rules at each date and location can have as arguments, at most, the messages sent between the two agents at that date and location. That is, there is no communication across locations at a given date. Further, the messages sent at a given date and location cannot be written down. Indeed, it is supposed that there is no paper of any kind and no storable commodities. Of course households at date 2 might claim any history of communication they like, but these claims will just constitute another contemporaneous date 2 message. Thus, much as before, households may, without loss of generality, be restricted to announcing contemporary shocks.

Not surprisingly, to the extent that the technology of communication is entirely oral and limited to the two locations, mutually beneficial trade is made difficult, if not impossible. This is illustrated with the example economy of this section. For suppose that agents a and a' alone suffer random endowments, with privately-observed, beginning-of-period realizations. That is, let θ^{a}_{1t} and $\theta^{a'}_{2t}$, t=1,2, denote the endowments of agents a and a' at their respective locations, 1 and 2, at date t. Suppose also that agents b and b' have nonrandom (public) endowments W^{b}_{it}, $W^{b'}_{it}$ t=1,2, respectively. Then, to determine an optimal allocation, it is enough to find a tax-subsidy transfer system π^{s}_{it}, π^{τ}_{it} for each location i, i=1,2, and each date t, t=1,2, which solve a fairly complicated looking programming problem; here π^{τ}_{11} has as its argument θ^{a}_{11}; π^{s}_{11} has as its argument θ^{a}_{11} and τ_{11}; π^{τ}_{12} has as its argument θ^{a}_{12}.

and so on. But the incentive constraints in this programming problem contain no intertemporal links, and so solving this programming problem quickly reduces to solving four separate but identical versions of Problem 1 in the previous section, corresponding to the meetings of a and b at location 1; date 1, a and b′ at location 1, date 2; and so on. Thus, if utility functions and endowments for each of these pairings are such that the no trade case of Figure 1 prevails, then indeed there can be no mutually beneficial trade whatever.

5. THE GAIN FROM INTERTEMPORAL LINKS WHEN INFORMATION IS PRIVATE

The rather disastrous outcome of the previous section could be avoided if agent pairings were repeated in the second period, as if agents b and b′ remained at locations 1 and 2 respectively or returned there at the beginning of the second period. Indeed, suppose for simplicity that this is possible if some amount K of the consumption good is used up in the second period, say disappearing from the endowments of agents b and b′ respectively, and suppose also for simplicity that no trades are conducted at what would have been the new trading location at date t=2, e.g., agent b at location 2, though such trades must have been the motive for travel. Finally, suppose also that agents a and a′ are identical as regards preferences and endowments, that is, each has the same intertemporal utility function and faces the same distribution of endowment realizations, with beginning-of-period realizations private to the individual. Similarly, suppose agents b and b′ are identical in that sense. Thus, we can focus on the pairing between agents a and b (or, equivalently, a′ and b′) and ignore the location subscript and, in part, the a superscript.

In the first period, we may suppose, without loss of generality, that agent a is to announce some endowment realization θ_1, effecting a random tax-subsidy transfer, $\pi^\tau_1(\theta_1)$, $\pi^s_1(\theta_1,\tau_1)$. In the second period we may suppose, without loss of generality, that agent a is to announce some second-period endowment realization θ_2. But with first-period announcements (and transfers) now known by both parties, these second-period announcements of θ_2 can effect random tax-subsidies, $\pi^\tau_2(\theta_1,\theta_2,\tau_1,s_1)$ and,

$\pi^{s}_{2}(\theta_1,\theta_2,\tau_1,s_1,\tau_2)$, which depend on first-period announcements and realizations. After all, these first-period announcements and realizations are known by both agents in the second period, and so we suppose they can commit themselves to second-period tax-subsidy rules which are accordingly indexed. Finally, we may suppose that announcements are made truthfully in each period, leading to a new problem,

Programming Problem 2:

Maximize

$$\omega^{a}\Big\{\sum_{\theta_1}\mathrm{Prob}(\theta_1)\sum_{\theta_2}\mathrm{Prob}(\theta_2)\iiiint\{U^{a}[\theta_1-\tau^{a}_{1}+s^{a}_{1}]+\beta U^{a}[\theta_2-\tau^{a}_{2}+s^{a}_{2}]\}$$

$$\pi^{s}_{2}(\theta_1,\theta_2,\tau_1,s_1,\tau_2,ds_2)\pi^{\tau}_{2}(\theta_1,\theta_2,\tau_1 s_1,d\tau_2)\pi^{s}_{1}(\theta_1,\tau_1,ds_1)\ \pi^{\tau}_{1}(\theta_1,d\tau_1)\Big\}$$

$$+\omega^{b}\Big\{\sum_{\theta_1}\mathrm{Prob}(\theta_1)\sum_{\theta_2}\mathrm{Prob}(\theta_2)\iiiint\{U^{b}[W_1-\tau^{b}_{1}+s^{b}_{1}]+\beta U^{b}[W_2-\tau^{b}_{2}\ +s^{b}_{2}-K]\} \tag{9}$$

$$+\pi^{s}_{2}(\theta_1,\theta_2,\tau_1,s_1,\tau_2,ds_2)\pi^{\tau}_{2}(\theta_1,\theta_2,\tau_1,s_1,d\tau_2)\pi^{s}_{1}(\theta_1,\tau_1,ds_1)\ \pi^{\tau}_{1}(\theta_1,d\tau_1)\Big\}$$

by choice of measure $\pi^{s}_{t}(\bullet)$ and $\pi^{\tau}_{t}(\bullet)$, t=1,2.

Here the second-period incentive constraint, given some history (θ_1,τ_1,s_1), given some current endowment realization θ_2, for a possible counterfactual endowment claim ϕ_2, is that either

$$\pi^{\tau}_{2}(\theta_1,\phi_2,\tau_1,s_1)\not\subseteq T(\theta_2) \tag{10}$$

or

$$\iint U^{a}[\theta_2-\tau^{a}_{2}+\ s^{a}_{2}]\ \ \pi^{s}_{2}(\theta_1,\theta_2,\tau_1,s_1,\tau_2,ds_2)\pi^{\tau}_{2}(\theta_1,\theta_2,\tau_1,s_1,d\tau_2)\ \geq$$

$$\iint U^{a}[\theta_2-\tau^{a}_{2}\ +\ s^{a}_{2}]\pi^{s}_{2}(\theta_1,\phi_2,\tau_1,s_1,\tau_2,ds_2)\pi^{\tau}_{2}(\theta_1,\phi_2,\tau_1,s_1,d\tau_2). \tag{11}$$

The first-period incentive constraint, given some endowment realization θ_1, for some counterfactual endowment claim ϕ_1 is either

$$\pi_1^{\tau}(\phi_1) \notin T(\theta_1) \tag{12}$$

or

$$\sum_{\theta_2} \text{Prob}\,(\theta_2) \iiiint \{U^a[\theta_1 - \tau_1^a + s_1^a] + \beta U^a[\theta_2 - \tau_2^a + s_2^a]\}$$

$$\pi_2^s(\theta_1, \theta_2, \tau_1, s_1, \tau_2, ds_2)\; \pi_2^{\tau}(\theta_1, \theta_2, \tau_1, s_1, d\tau_2) \pi_1^s(\theta_1, \tau_1, ds_1) \pi_1^{\tau}(\theta_1, d\tau_1) \quad \geq$$

$$\sum_{\theta_2} \text{Prob}\,(\theta_2) \iiiint \{U^a[\theta_1 - \tau_1^a + s_1^a] + \beta U^a[\theta_2 - \tau_2^a + s_2^a]\} \tag{13}$$

$$\pi_2^s(\phi_1, \theta_2, \tau_1, s_1, \tau_2, ds_2) \pi_2^{\tau}(\phi_1, \theta_2, \tau_1, s_1, d\tau_2) \pi_1^s(\phi_1, \tau_1, ds_1) \pi_1^{\tau}(\phi_1, d\tau_1)$$

(Here of course $T(\theta_2)$ is a adjusted to take into account that the endowment of agent b is diminished by K).

The solution to Problem 2 will generally entail some nontrivial exchange, even under endowment/preference specifications that make the solution to Problem 1 autarkic. This should be true even for fairly large resource costs K. The key, of course, is the possibility of intertemporal links, with second-period transfers dependent on first-period claims. For example, pure borrowing-lending agreements are possible and mutually beneficial; if agent a's endowment is low in the first date, for example, let him borrow from agent b and promise to repay the loan at the second date. Of course, an optimum will almost surely mix such borrowing-lending agreements with some form of risk-sharing, as is argued in more detail in Townsend [1982]. And quite possibly, with some nontrivial time dependence in the stochastic process for the endowment θ_t, agents will make use of double transfers systems, since quantities convey information about future performance.

6. INCENTIVE COMPATIBLE ARRANGEMENTS WITH INTERMITTENT MEETINGS: ON PERSON-SPECIFIC ASSIGNMENT SYSTEMS

The optimal arrangements described in Section 4 may seem limited, and the return-to-home-base model of Section 5 may seem demanding, relative to our prior about location-specific, oral assignment systems. Perhaps a trade is made possible under oral assignment systems if only agents deal with one another on an intermittent basis. This section makes formal that idea and shows how intermediaries or person-specific assignment systems might emerge. In the end, though, oral assignment systems are still shown to be somewhat limited.

To proceed, then, consider a simple three period, three agent, two location economy with exogenous pairings described by Table 2.

location	1	2
date 1	(a,b)	(c)
2	(b,c)	(a)
3	(a,b,c)	ϕ

TABLE 2

Note that in this economy all essential meetings take place at the first location, and so again we may ignore the location subscript. Also, suppose for simplicity that agent a alone has a random endowment vector, and only at date 1, denoted θ_1^a. Otherwise, let W_t^j denote the endowment of agent j at date t, a publicly observed vector. The notation for preferences is as above. Finally note that agent b stays at location 1, so he may be interpreted in this example economy as a banker or intermediary.

Without loss of generality agent a in this setup may be restricted to announcing θ_1^a at the beginning of date 1, though we shall have to ensure that he announces truthfully. Notationally, then, the lotteries $\pi_1^{\tau}(\theta_1^a)$ on taxes $\tau_1 = (\tau_1^a, \tau_1^b)$ and $\pi_1^s(\theta_1^a, \tau_1)$ on subsidies $s_1 = (s_1^a, s_1^b)$ are indexed by those announcements. Also, because agents a and b are together again at date 3 the lotteries at date 3 on taxes $\tau_3 = (\tau_3^a, \tau_3^b, \tau_3^c)$, and on subsidies $s_3 = (s_3^a, s_3^b, s_3^c)$ are indexed by θ_1^a announcements as well and also by first period transfers τ_1 and s_1. That is, as in Harris-Townsend [1981], since two agents, a and b, know the announcement of θ_1^a and the transfers τ_1 and s_1 at date 3, this information can be made public at date 3 in a carefully constructed matrix game.

Continuing, suppose agent b (the intermediary) makes announcements at date 2 about θ_1^a announcements at date 1 and also about transfers τ_1 and s_1 at date 1, the performance of his portfolio, as it were. Also suppose the date 2 lottery rules determining taxes $\tau_2 = (\tau_2^b, \tau_2^c)$ and subsidies $s_2 = (s_2^b, s_2^c)$ are indexed by such date 2 announcements of agent b. Now since agent a is not present at date 2, the date 1 θ_1^a announcements of agent a and the date 1 transfers τ_1 and s_1 are not public at date 2, and agent b must be given an incentive to announce truthfully. On the other hand, both agents b and c are together again at date 3 and so date 3 tax-subsidy lottery rules can be indexed by the second-period announcement of first-period announcement θ_1^a and first-period transfers τ_1 and s_1 directly. In the end, then, lotteries $\pi_2^{\tau}(\theta_1^a, \tau_1, s_1)$, $\pi_2^s(\theta_1^a, \tau_1, s_1, \tau_2)$ at date 2 are indexed by the announcements of agent b at date 2, and the lotteries $\pi_3^{\tau}(\theta_1^a, \tau_1, s_1; \theta_1^a, \tau_1, s_1; \tau_2, s_2)$, $\pi_3^s(\theta_1^a, \tau_1, s_1; \theta_1^a, \tau_1, s_1; \tau_2, s_2, \tau_3)$ at date 3 are indexed by both the announcements of agent a and transfers at date 1, hence the first triplet, and the announcement of agent b and transfers at date 2, hence the second triplet. Finally, the incentive constraint of agent b at date 2 is of the form

$$\iiiint\!\!\int \left\{ U^b(W_2^b - \tau_2^b + s_2^b) + \beta\, U^b(W_3^b - \tau_3^b + s_3^b) \right\}$$

$$\pi_2^s(\theta_1^a, \tau_1, s_1, \tau_2, ds_2)\, \pi_2^{\tau}(\theta_1^a, \tau_1, s_1, d\tau_2)$$

$$\pi_3^s(\theta_1^a, \tau_1, s_1; \theta_1^a, \tau_1, s_1; \tau_3, \tau_2, s_2, ds_3)\, \pi_3^{\tau}(\theta_1^a, \tau_1, s_1; \theta_1^a, \tau_1, s_1; \tau_2, s_2, d\tau_3)$$

$$\geq \iiiint \Big\{ U^b(W_2^b - \tau_2^b + s_2^b) + \beta U^b(W_3^b - \tau_3^b + s_3^b) \Big\}$$

$$\pi_2^s(\bar{\theta}_1^a, \bar{\tau}_1, \bar{s}_1, \tau_2, ds_2)\ \pi_2^\tau(\bar{\theta}_1^a, \bar{\tau}_1, \bar{s}_1, d\tau_2) \tag{14}$$

$$\pi_3^s(\theta_1^a, \tau_1, s_1;\ \bar{\theta}_1^a, \bar{\tau}_1, \bar{s}_1;\ s_2, \tau_2, \tau_3, ds_3)\pi_3^\tau(\theta_1^a, \tau_1, s_1;\ \bar{\theta}_1^a, \bar{\tau}_1, \bar{s}_1;\ s_2, \tau_2, d\tau_3)$$

where the $\bar{}$ in (14) denote possible counterfactual announcements of (θ_1^a, τ_1, s_1).

Equation (14) makes clear that in general, unlike the outcome in Section 4, the transfers <u>at date 2</u> can indeed be indexed in a nontrivial way by the θ_1^a announcement, and in that sense intermittent meetings do help overcome the limitations of oral communication. On the other hand, there are still limitations—equation (14) does impose limits on the extent to which allocations can be indexed.

7. <u>AN INTERPRETATION OF LOCATION- OR PERSON-SPECIFIC ASSIGNMENT SYSTEMS</u>

In view of contemporary financial institutions and markets, we may be unaccustomed to thinking about location-specific or person-specific assignment systems as a dominant form of economic organization. But economic history does provide some examples. One example is the form of banking in Europe during the initial stages of the Commercial Revolution, from the 10th to the 15th centuries, in Barcelona, Bruges, or the fairs at Champagne, for example, as described by Usher (1943) and DeRoover (1948). Apparently, in these places an agent could open an account with a banker but to transfer the account to some third party, for example, as the result of a purchase at the local market or fair, both the initial agent and the third party had to return to the bank where, in effect, under their instructions, two separate bilateral transactions with the banker took place. Accounts were kept in a written ledger, apparently as an aid to memory and for evidence in potential legal proceedings. But writing played no role for transfers outside the bank. Apparently, similar location-specific assignment systems were used in Genoa, for example, to transfer the ownership of shares to commercial trading ventures and of annuities based on municipal tax revenues. In fact, on reflection, it seems that location-specific assignment systems have been used in more recent history, as with the registrars of land titles or deeds, for example.

As for person-specific assignment systems, it is sometimes difficult to distinguish these from location-specific assignment systems. In fact, the medieval bankers referred earlier were mobile, setting up their tables for business on a day-by-day basis and occasionally traveling to the fairs of Champagne from Italy.

Still, though the present paper might help us to understand the role of location- or person-specific assignment systems, such as banking systems, once they are in place, it should be stressed that this paper does not purport to offer a theory of assignment systems or banks. That is, it does not describe the circumstances under which a particular assignment system would have force relative to alternative social arrangements. Thus, the paper does not explain who might emerge as a banker and under what circumstances. One suspects that aspects of limited commitment and enduring relationships are needed for such explanations, but that remains beyond the scope of the present effort.

8. PORTABLE OBJECTS AS RECORD-KEEPING DEVICES

The next step up in the hierarchy of communication in spatial settings would seem to be the use of portable record keeping devices, tangible but concealable physical objects which can be used as evidence of past transactions or actions. Indeed, to think about this idea formally consider again the 4-agent, two-period, two-location economy of Section 4. But suppose now the existence of portable concealable objects in the form of tokens, that is, objects which can be carried about by the agents and hence stored from period to period. Also suppose for simplicity that these objects are intrinsically useless, that is, do not enter into anyone's utility function. Finally, suppose that the production and transfer rules for these tokens is the subject of complete public control, though again, with location shifts, individual holdings may be private to individuals. Under these assumptions, individual token holdings, though private to the individual, constitute state variables which can be announced by the individual and thus subjected to contingent taxes and subsidies, just as commodity endowments were earlier in the paper. In this way, then, contemporary transfers can be made at least partially contingent on individual token holdings and hence contingent on past transactions. Indeed, as we have already seen, intertemporal links like this, however imperfect, can allow mutually beneficial arrangements in situations where otherwise arrangements would be quite limited.

As it turns out, the analysis and notation of this section can be facilitated considerably by the assumption that agents a and a' are symmetric in endowments and preferences, as described earlier, and also agents b and b' respectively, and that further agents b and b' are risk-neutral. Under these assumptions, though agents b and b' could carry individual tokens in order to make second-period transfers functions of the first-period histories they have experienced, in an optimal arrangement they will not do so. Any such variations in second-period consumptions could be smoothed out entirely by agents b and b' without any loss of utility and, more to the point, without any adverse effect on individual incentives; after all, only agents a and a' are supposed to suffer privately observed endowment shocks in the first period. The end result, then, is that we need only be concerned with tokens carried by agents a and a'. Finally, under the symmetry assumptions and the requirement that agents a and a' receive equal weight in the social optimum, and similarly for agents b and b' respectively, the programming problem for determining a social optimum in the 4-agent, two-period, two-location economy can be reduced to a programming problem for an apparent 2-agent, one-location economy consisting say of just agents a and b; that is the primes on variables may be deleted for simplicity.

More formally, then, one needs only to distinguish taxes and subsidies on the consumption goods from taxes and subsidies on tokens and to keep track of token balance holdings. That is, given an endowment realization θ_1 and initial currency holdings M_1 of agent a, first-period token taxes τ^a_{1c} and τ^b_{1c} on agents a and b, respectively, are feasible if $0 \leq \tau^a_{1c} \leq \theta_1$, $0 \leq \tau^b_{1c} \leq W_1$, and the first-period token tax τ_{1m} (on agent a alone) is feasible if $0 \leq \tau_{1m} \leq M_1$ where τ_{1m} is restricted to integer values, consistent with our interpretation of currency as pieces of paper. Let $T_1(\theta_1)$ denote the space of possible probability measures over such taxes $\tau_1 = (\tau^a_{1c}, \tau^b_{1c}, \tau_{1m})$ given the endowment realization θ_1 and let $\pi^\tau_1(\theta_1)$ denote the measure used for the announcement θ_1. First-period consumption subsidies s^a_{1c} and s^b_{1c} on agents a and b, respectively, are feasible if $s^a_{1c} \geq 0$, $s^b_{1c} \geq 0$, $s^a_{1c} + s^b_{1c} \leq \tau^a_{1c} + \tau^b_{1c}$, and the first-period token subsidy (on agent a alone) is feasible if $s_{1m} \geq 0$, again with the restriction to integer values. Let $S_1(\tau_1)$ denote the space of possible probability measures over such subsidies $s_1 = (s^a_{1c}, s^b_{1c}, s_{1m})$ and let $\pi^s_1(\theta_1, \tau_1)$ denote the conditional measure used for the endowment announcement θ_1 and first-round tax τ_1. Similarly, second-period consumption taxes τ^a_{2c} and τ^b_{2c} are feasible if $0 \leq \tau^a_{2c} \leq \theta_2$, $0 \leq \tau^b_{2c} \leq W_2$, as before. The second-period token tax (on agent a alone) is feasible if $0 \leq \tau_{2m} \leq M_2(\tau_{1m}, s_{1m}) \equiv M_1 - \tau_{1m} + s_{1m}$. Let $T_2(M_2, \theta_2)$ denote the space of feasible probability measures over such taxes $\tau_2 = (\tau^a_{2c}, \tau^b_{2c}, \tau_{2m})$, conditional on beginning of second-period token balances, M_2, and second-period endowment realization, θ_2, and let $\pi^\tau_2(M_2, \theta_2)$ denote the second-period conditional measure used, again with the stated conditioning elements. Second-period consumption subsidies s^a_{2c}, s^b_{2c} are feasible if $s^a_{2c} \geq 0$ $s^b_{2c} \geq 0$, $s^a_{2c} + s^b_{2c} \leq \tau^a_{2c} + \tau^b_{2c}$, and here we can ignore the second-period token subsidy (on agent a alone). Let $S_2(\tau_2)$ denote the space of feasible probability measures over such subsidies $s_2 = (s^a_{2c}, s^b_{2c})$ with the stated conditioning elements, and let $\pi^s_2(M_2, \theta_2, \tau_2)$ denote the conditional second-period measure. Again exploiting the symmetry assumptions and assuming agents a and a' receive equal weight in a social optimum, and similarly for b and b', we are now able to write down a programming problem for the determination of a social optimum,

Programming Problem 3:

Maximize

$$\omega^a \left\{ \sum_{\theta_1} \text{Prob}(\theta_1) \sum_{\theta_2} \text{Prob}(\theta_2) \iiiint U^a[\theta_1 - \tau^a_{1c} + s^a_{1c}] + \beta U^a[\theta_2 - \tau^a_{2c} + s^a_{2c}] \right.$$

$$\left. \pi^s_2[M_2(\tau_{1m}, s_{1m}), \theta_2, \tau_2, ds_2]\, \pi^\tau_2[M_2(\tau_{1m}, s_{1m}),\ \theta_2, d\tau_2]\, \pi^s_1(\theta_1, \tau_1, ds_1)\, \pi^\tau_1(\theta_1, d\tau_1) \right\}$$

$$+\omega^b \left\{ \sum_{\theta_1} \text{Prob}(\theta_1) \sum_{\theta_2} \text{Prob}(\theta_2) \iiiint U^b[W_1 - \tau^b_{1c} + s^b_{1c}] + \beta U^b[W_2 - \tau^b_{2c} + s^b_{2c}] \right. \tag{15}$$

$$\left. \pi^s_2[M_2(\tau_{1m}, s_{1m}), \theta_2, \tau_2, ds_2]\, \pi^\tau_2[M_2(\tau_{1m}, s_{1m}),\ \theta_2, d\tau_2]\, \pi^s_1(\theta_1, \tau_1, ds_1)\, \pi^\tau_1(\theta_1, d\tau_1), \right\}$$

by choice of $\pi^\tau_1(\bullet)$ $\pi^s_1(\bullet)$ $\pi^\tau_2(\bullet)$ $\pi^s_2(\bullet)$, and subject to certain incentive compatibility constraints. For these, let M_2 denote the (finite) set of beginning-of-second-period token balances, all holdings $M_2(\tau_{1m}, s_{1m})$ which are possible given the family of probability measures $\pi^\tau{}_1(\theta_1)$, $\pi^s{}_1(\theta_1, \tau_1)$, that is, possible for some realization θ_1 and for some realization of the lotteries π_1. Then the incentive constraint in the second period, if beginning-of-period token balances are actually M_2 and the second-period endowment is actually θ_2, for some counterfactual token holding, endowment announcement (N_2, ϕ_2), is of the form either

$$\pi^\tau{}_2(N_2, \phi_2) \notin T_2(M_2, \theta_2), \tag{16}$$

so that $\pi^\tau{}_2(N_2, \phi_2)$ is not feasible given M_2 and θ_2 or

$$\beta \iint U^a[\theta_2 - \tau^a_{2c} + s^a_{2c}]\ \pi^s_2(M_2, \theta_2, \tau_2,\ ds_2)\ \pi^\tau_2(M_2, \theta_2, d\tau_2)$$

$$\geq \beta \iint U^a[\theta_2 - \tau^a_{2c} + s^a_{2c}]\ \pi^s_2(N_2, \phi_2,\ \tau_2, ds_2)\ \pi^\tau_2(N_2,\ \phi_2, d\tau_2) \tag{17}$$

so that the announcement (M_2, θ_2) is weakly preferred. Similarly, the incentive constraint in the first period if the endowment realization is actually θ_1, for some counterfactual endowment announcement ϕ_1, is of the form either

$$\pi^\tau{}_1(\phi_1) \notin T_1(\theta_1) \tag{18}$$

or

$$\sum_{\theta_2} \text{Prob}\,(\theta_2) \iiiint \{U^a[\theta_1 - \tau^a_{1c} + s^a_{1c}] + \beta U^a[\theta_2 - \tau^a_{2c} + s^a_{2c}]\}$$
$$\pi^s_2[M_2(\tau_{1m}, s_{1m}), \theta_2, \tau_2, ds_2]\,\pi^\tau_2[M_2(\tau_{1m}, s_{1m}), \theta_2, d\tau_2]\,\pi^s_1(\theta_1, \tau_1, ds_1)\,\pi^\tau_1(\theta_1, d\tau_1)$$
$$\geq \sum_{\theta_2} \text{Prob}(\theta_2) \iiiint \{U^a[\theta_1 - \tau^a_{1c} + s^a_{1c}] + \beta U^a[\theta_2 - \tau^a_{2c} + s^a_{2c}]\}$$
$$\pi^s_2[M_2(\tau_{1m}, s_{1m}), \theta_2, \tau_2, ds_2]\,\pi^\tau_2[M_2(\tau_{1m}, s_{1m}), \theta_2, d\tau_2]\,\pi^s_1(\phi_1, \tau_1, ds_1)\,\pi^\tau_1(\phi_1, d\tau_1). \qquad (19)$$

This completes the specification of Problem 3.

A comparison of Problem 3 with Problem 2 reveals the sense in which the ~~currency~~ Token system may be a *limited* communication system. The environment which generates Problem 2 allows the agents to kept track of past histories or, more precisely, to use the complete historical record in effecting contemporary trades. That is, second-period lotteries can be indexed by the first-period history, θ_1 (as well as by realizations of the first period lotteries). Thus, there is a different family of possible lottery choices for every possible history. In Problem 3, however, contemporary lotteries are indexed by beginning-of-period ~~currency~~ Token balances, and these are private information. Thus, we cannot insist that agents with different histories be treated differently. It is always possible for an agent to claim to have less ~~currency~~ Tokens than he actually does, thereby gaining access to the family of lottery choices intended for someone with a different history. With more than one commodity, for example, he may well want to do this.[6] The effect of this confounding, of course, is to limit the extent to which families of lotteries can be differentiated, thereby limiting mutually beneficial trade.

[6] With a single good it is possible that individual token holdings may reveal past histories competely. For example, if agent a "lends" the single good in period one, let him receive a positive number of tokens and let him receive zero tokens otherwise, when he "borrows". Then, insist that borrowing be "repaid" in the second period in the event that agent a cannot support a tax on individual token holdings. With two goods, however, agent a may be a "borrower" of one commodity and a "lender" of the other, with a decision to repay one good or the other contingent on second-period endowments. In such circumstances, with positive probability, agent a might want to understate token holdings regardless of whether large holdings were associated with the lending of the first good, or the other way around.

9. A MORE LIMITED ROLE FOR BONA FIDE COMMODITY TOKENS

We might consider in passing what role bona fide commodity tokens might play in these worlds with private information and limited communication. Suppose now, unlike the analysis of the previous section, there is no role for artificial, intrinsically useless objects which can serve as tokens, say due to counterfeiting possibilities. One's intuition is that bona fide commodity tokens can still serve to (partially) distinguish past histories, just as intrinsically useless tokens do, and, as such, bona fide commodity portable object systems can still be viewed as limited communication systems. On the other hand, the role of portable commodity tokens would seem to be more limited than that of intrinsically useless tokens, since a commodity in the second period is the same, whether achieved by storage or by the realization of a contemporary endowment. Further, any effort to use storage as a communication device would necessarily affect intertemporal allocations and thus might well introduce distortions, moving the system away from a private information optimum with less restricted communication. Thus one might want to make limited use of a limited device.

To formalize this intuition, then, suppose we allow the possibility of commodity storage in discrete units and consider as a basis for future comparisons how programming problem 2 would be altered on the assumption that there is no difficulty in communicating past histories. Given an endowment announcement θ_1 and conditional on a first-round transfer τ_1 under lottery $\pi_1^{\tau}(\theta_1)$ and conditional on a second-round subsidy s_1 under lottery $\pi_1^{s}(\theta_1, \tau_1)$, we might envision a third-round lottery specifying a storage decision i_1, say a lottery $\pi^{i}(\theta_1, \tau_1, s_1)$, assuming, for simplicity, that such decisions are clearly observed at the time they are taken. Similarly, the second-period lotteries should be indexed by first-period announcements θ_1, transfers τ_1, s_1, and storage decisions i_1 as well as by the natural second-period state variable $\theta_2 + i_1$, as the latter determines the individual's decisions or announcements. Thus we are in search of lotteries $\pi_2^{\tau}(\theta_1, \theta_2 + i_1, \tau_1, s_1, i_1)$ and $\pi_2^{s}(\theta_1, \theta_2 + i_1, \tau_1, s_1, i_1, \tau_2)$ much as before.

Now consider how we might alter programming Problem 3 when there is limited communication across locations or time periods so that there may be some role for commodity tokens. Here then first period announcements θ_1 transfers τ_1 and s_1, and storage decision i_1 would <u>not</u> be known automatically at date 2. With no intrinsically useless tokens, $\theta_2 + i_1$ is the only natural unobserved state variable since again this alone determines individual actions or announcements at the beginning of date 2. Thus we are in search, second-period lotteries $\pi_2^{\tau}(\theta_2 + i_1)$, $\pi_2^{s}(\theta_2 + i_1, \tau_2)$ as well as first-period lotteries $\pi_1^{\tau}(\theta_1)$, $\pi_1^{s}(\theta_1, \tau_1)$, $\pi_1^{i}(\theta_1, \tau_1, s_1)$. The point is that there is a confounding of the information content of i_1 about θ_1 with the period two information about θ_2. Two extreme cases help make the point. Suppose on the one hand the endowment θ_2 were in fact some constant. Then storage decisions, in varying with θ_1, could help to distinguish states θ_1. On the other hand, if i_1 were a constant, then states θ_2 might be partially distinguished. In general, then, with θ_2 random and i_1 nonconstant we would have only limited ability to distinguish first- and second-period endowment realizations. Further, the storage decision i_1 almost surely varies as between modified problem 2 and modified problem 3 and in that sense the use of commodity tokens would involve intertemporal distortions which might well limit their use.

10. A ROLE FOR MULTIPLE PORTABLE OBJECTS

Now consider an increase in the level of communication permitted by the technology of the economy and suppose that there are intrinsically useless tokens of different colors, that these can be distinguished by the agents, and that there is no counterfeiting. It is virtually immediate that communication possibilities are somewhat improved. For consider how Problem 3 would be altered by the existence of two tokens, say green and red. In this case, there would be two beginning-of-second-period, privately observed, token-balance state variables as well as beginning-of-second-period, privately observed, endowment state variables. Thus the tax-subsidy lotteries on the consumption good and the tax-subsidy lotteries on the two tokens could be indexed to announcements of these state variables. Indeed, suppose the endowment θ_1 can take on two values each period. That is, $\Theta = \{\theta', \theta''\}$. Then if agent a announces $\theta_1 = \theta'$ in period 1, let him pay a tax in red token.[5] Similarly, if agent a announces $\theta_1 = \theta''$ in period 1, let him pay a tax in green token. These two outcomes yield what we may term a high green, low red beginning-of-period token state, and a low green, high red beginning-of-second-period token state, respectively. Now at the beginning of the second period, let agent a announce one of these two token states. If he announces high green, low red, let him pay a tax in green token[5] exceeding the value of green token balances in the low green, high red state, and conversely if he announces the low green, high red state. Clearly, the announcement of high green, low red is not feasible if agent a announced $\theta_1 = \theta''$ in period 1, and conversely for the announcement low green, high red with $\theta_1 = \theta'$. In this way, histories of past announcements are in effect public information in the second period, and we have a virtually complete intertemporal communication system. More generally, a sufficient condition which achieves this result with the 2-person example economy is that there be as many different colored tokens as there are values of θ_1 in the first period (with more periods, we would need more colored tokens, to distinguish longer histories).

11. AN INTERPRETATION OF PORTABLE OBJECT SYSTEMS

On the face of it, the use of portable objects as communication devices or "signals" would seem to be commonplace. For example, an agent presents himself to a potential client with a fine suit of clothes or an expensive automobile, as if revealing past successful actions or desirable attributes. But of course the client might suspect some "swindle", and, more generally, portable objects have force as signals or records of specific histories only to the extent that they cannot be (easily) acquired in other ways. This requires that a group of agents which is to use a portable object as a communication device be able to implement strict controls over the production of the device and over the transfer of it from one person to another. Of course such control <u>is</u> assumed in the theory of this paper. In practice, and in a more elaborate theory, such control is not so easily obtained or explained.

The theory of this paper does suggest, though, that we might expect to see the use of portable object commodity systems in more or less close-knit societies with prominent aspects of spatial separation and otherwise limited communication. In this regard one is tempted to cite anthropological studies on apparent multiple token systems in use in so-called primitive societies.

One such study was done in 1924 by W.E. Armstrong on Rossel Island, a virtually self-sufficient economy in the Southwest Pacific (see Baric (1964)). According to Armstrong, natives of the Island were accustomed to use up to two types of shells and up to 38 subcategories of shells in various "exchange" transactions. Exchanges took place with great ceremony in a variety of different contexts, and each exchange was viewed as distinctive, requiring a prespecified transfer of a specific subcategory of shell. Further, shells were not interchangeable or substitutable in these transactions, or elsewhere; they were not multiples of one another. The gathering and manufacture of some of these shells were again highly ceremonial and closely guarded, while other shells were essentially fixed in supply, regarded as being made by a chief deity before man's arrival.

A more celebrated, dramatic, albeit controversial anthropological study of this sort was done by Bronislaw Malinowski from 1914-1920 on the Kula exchange system, in use in Eastern New Guinea and a "ring" of adjacent islands. The natives in each of these islands would periodically embark on great canoe trading expeditions, traveling essentially to the north or to the south. Upon arrival at an island to its north, the expedition would give up some of its commodity cargo as "gifts" and receive as "gifts" arm bracelets made of white shell. Alternatively, upon arrival at an island to its south, commodity "gifts" were reciprocated with long necklaces made of red shells. In fact, every person in the Kula system stood in some prespecified direction, either north or south, to each of his Kula trading partners, both across islands, for these trading expeditions, and within islands, for more continuous "exchange". Thus, white armbands circulated counterclockwise throughout the ring of islands, and red necklaces circulated clockwise. Again, all these "exchanges" took place with great ceremony. The shells were distinctive, each with its own history. And the supply of shells generally was closely guarded. Apparently, then, natives in these islands were using shells to keep track of two characteristics--the direction of trade and the magnitude of trade. That is, an individual in possession of white shells could reveal that he had at one time been a net exporter of commodities to the north.

Continuing this line of reasoning, one is tempted to interpret the fiat currency systems of modern industrial economies as further instances of the use of economy-wide communication systems in the sense of the theory of this paper. Under this interpretation one occasionally finds multiple token systems, e.g., the use of food coupons as well as standard currency in wartime England. But for the most part standard currency systems would be viewed as single token systems. Of course one should resist this interpretation to the extent that one is uneasy with a contract-theoretic approach to explaining the institutions of large industrial economies. In particular this paper fails to include limited commitment as a key part of the theory, and yet limited commitment must explain the early use in Europe, for example, of bona fide commodity currencies, e.g., gold and silver, especially for interregional transactions. Such limited commitment would limit the use of currency as a communication device and enhance the role of currency as a store value as in the spatial models of Townsend (1980).

12. WRITTEN MESSAGE SYSTEMS

Now go one step further in the communication technology hierarchy, supposing the existence of written messages. That is, suppose agents can carry with them written messages on paper describing their past announcements and transfers at particular dates and places, suppose these written messages must be displayed at future dates and possibly distinct locations in order to effect an allocation of resources, and suppose that this system is not subject to fraud. Indeed, to think about this more formally, consider again the 4-agent, two-period, two-location economy which generates problem 3. Imagine as usual that agents a, a', b, and b' have formed a trading partnership. Now suppose, for example, that agent a were to want to borrow from agent b in the first period, say because θ_1 were low. Suppose this transaction were recorded on paper and suppose that agent a were required to show the paper to agent b' on the latter's arrival in the second period. This would entitle him directly to the family of lotteries indexed by θ_1. More generally, then, agent a would have on hand a piece of paper noting his first-period announcement of θ_1 and the subsequent transaction, the taxes and subsidies, τ_1 and s_1 respectively. These would then be public information, and there would be no issue of understating "past histories." Thus, the trade-inhibiting effect of the incentive compatibility constraints in problem 3 would be weakened, allowing in general a Pareto superior solution. Indeed, here, with the symmetry conditions for agents a and a', and for b, and b', and neutrality for b and b', one generates problem 2 as is agents a and b remained paired with one another without incurring any resource cost K. Generally then, apart from special cases, communication systems with reliable written messages Pareto dominate communication systems with portable concealable token objects.

13. AN INTERPRETATION OF WRITTEN MESSAGE SYSTEMS

Written message systems are commonplace, used in both "small" and "large" groups of agents as well as in historical and contemporary structures. Typical examples include the use of checks in which a banker is informed of a transaction outside the bank, an intended transfer of an account executed at a specified date and distinct, outside location. Related is the use in firms of nonnegotiable bills of exchange, in Western Europe in the 15th century, for example, as described by Usher (1943) and DeRoover (1948). Typically, a businessman in Bruges, for example, would accept (or borrow) currency from an "outside" agent and then send a written message to his partner in an Italian city to pay the "outside" agent or the latter's partner there. This use of a written message over relatively long distances is virtually indistinct from a very local transaction in a discount store, in which a customer pays for goods at the checkout counter and is issued a written receipt, which is carried to a package pickup center for actual distribution. Also similar is a relatively local transaction in which a depositor of grain in a Chicago elevator is given a written receipt as evidence of the deposit, a receipt which could be passed in the 19th century, at least, to third parties. In a similar way bills of exchange eventually circulated in Europe to third, fourth, and nth parties, as did paper securities as well as bank notes.

Of course the theory of this paper does not purport to explain why some written message systems are viable and others not or the extent of circulation of written messages once they are in place. Again, it seems we should incorporate the possibility of default and some aspect of enduring relationships. And certainly with limited commitment, securities become valued as conveyors of purchasing power, a role distinct from their role in this paper, where they are simply messages of past events necessary to support a beneficial, multilateral arrangement.

14. TELECOMMUNICATIONS -- TOWARD A CENTRALIZED, ARROW-DEBREU WORLD

We come at last to the possibility of telecommunications — communications which do not have to be transported with people. The advantage of telecommunications, of course, is that transportation of people is generally costly or at least costly relative to telegraph and telephone systems. Thus telecommunications reduce communication costs, and allow in turn a more efficient allocation of resources.

An example economy, though at most suggestive, seems to illustrate these points. Thus imagine an economy consisting of one date (other than a planning period), five possible trading locations, and five agents, as depicted in Figure 2.

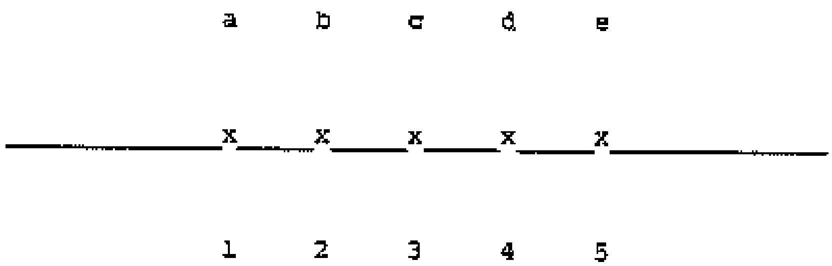

FIGURE 2

Here agent a is residing initially at location 1, agent b at location 2, c at 3, d at 4, and e at 5. Each of the agents a and e is subjected to a random (privately observed) endowment of a vector of consumption goods, and so, with strictly concave single-period utility functions, there are gains to risk-sharing and to intertemporal trade. But how are agents to communicate endowment realizations, or at least make claims about realizations? Without telecommunications, but with written instruments (and constant transportation costs), one arrangement would be for a to travel to b and for e to travel to d, for a and e to make claims which are recorded on paper, and then for b and d to travel to c with these instruments. Reversing these movements in space, it is, in the end, as if everyone had been together at the beginning of the period. Of course telecommunications also allow this possibility, presumably with the use of less resources. Finally, then, under either system, agents execute trades consistent with some <u>ex ante</u> planning period agreement. Of course this again requires some transportation, or at least some transport of goods. It seems likely, though, that with reasonable specifications of transportation and transport costs, the efficient use of written instruments would not have agents traversing much of the same ground twice, that initially goods as well as messages might be transported with people. In fact one wonders whether goods would traverse much of the same ground twice or whether agents might not settle for less limited forms of risk-sharing. (Note that it cannot be known what is to be transferred until b and d meet with c). Thus it seems likely that the system would display simultaneous transactions in financial instruments and commodities and would be limited relative to telecommunication systems.

Indeed, to see the rather radical transformations of financial structure and economic organization which telecommunication systems might allow, suppose telecommunications were costless. Then we would have come to a world in which, apart from claimed endowment realizations, commodities need only be indexed by date and location. Briefly, in such a world, agents would agree in the planning period to a resource allocation rule specifying transfers to each agent at each location and each date as a function of contemporary endowment announcements of all agents in all locations and the entire history of such announcements. Thus, all agents, regardless of their travels, would be tied to a centralized electronic record keeping system. There would be no essential dynamics, and financial instruments or financial markets as we have come to know them would cease to exist.

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