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Exchange and Specialisation as a Discovery Process

Exchange and Specialization as a Discovery Process

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Abstract

In this paper we study the performance of an economic environment that can support specialization if the participants implement and develop some system of exchange. We define a closed economy in which the participants must discover the ability to exchange, implement it, and ascertain what they are comparatively advantaged in producing. Many people demonstrate the ability to find comparative advantage, capture gains from trade, and effectively choose production that is consistent with the choices of others. However, many do not become specialists, even though full efficiency can only be achieved if everyone does so. Near-full efficiency does occur bilaterally in these economies, typically because some individuals have entered a stable trading relationship with a specialist in the other good. Such pairing does not necessarily give impetus to the formation of other pairs, nor are pairs open to the inclusion of a third party. We explore various treatments to provide insight into the conditions that might foster the growth of specialization and exchange within this austere institutional framework. We find one treatment that achieves high levels of efficiency in half of the sessions.

JEL Codes: C92, D51, F10

Key Words: specialization, exchange and production economies, experimental economics

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1. Introduction

Adam Smith is credited with clearly articulating the proposition that specialization creates wealth, and specialization is in turn supported by exchange. At the mid-twentieth century, theorists had elegant multiple commodity general equilibrium models of competitive markets based on preference/utility demand theory and resource production supply theory, that were believed to constitute the institution-free core of economics. This solved a long-standing theoretical problem: what are the fundamental static forces behind resource prices and allocations that explain their diversity in response to differing external circumstances, *given preferences and technology*?

But central new questions were not addressed. In particular, what does the individual need to know beyond his personal circumstances for specialization and exchange to be efficacious? Does each person need information on the circumstances of others? If not, what are the dynamics of that discovery process? All these questions have been explored by experimental methods under institutional exchange structures in which the participants were instructed in how to trade using the message and outcome rules of particular trading institutions. Consequently, under the conditions that *preferences, technology and institutions are all specified* by the experimenter, we have discovered what theory did not predict, that individuals need know nothing beyond their private circumstances and the action (property right) rules of the institution to achieve remarkably efficient outcomes over time, even in quite complex multiple market environments.

Left unanswered by both theory and experiment is the question: how might agents discover comparative advantage in an institutionally unstructured and informationally decentralized economy, and spontaneously learn to order their production and exchange decisions through emergent institutional or personal relationships that they create? This question—involving an unspecified dynamics of specialization and exchange—is at the core of human social discovery processes. Somehow in history humans created specialization, exchange, and their many supporting institutions through complex discovery processes. It was the genius of the Scottish Enlightenment—David Hume, Adam Smith, Adam Ferguson and others—that observed and described the existence of a "natural" social, legal and economic order consisting of "establishments, which are indeed the result of human action but not the execution of any human design…" (Ferguson, *Essays on Civil Society;* quoted in Buchan, p 223).

In this paper we report an experiment in which individuals are privately informed of their home production and consumption opportunities, must discover their potential to gain through specialization provided that they find and develop bilateral or multilateral trading relationships with others having complementary circumstances, and must rely on trust and repeat interaction to enforce agreements and develop their own institutional relations. The paper is a beginning experimental investigation of the question articulated by Carl Menger at the very dawn of the marginal and general equilibrium revolution: "How can it be that institutions that serve the common welfare and are extremely significant for its development come into being without a *common will* directed towards establishing them?" (Menger, 1985, p146; title text quoted in Hayek, 1988, p. 1)[1] The absence of relevant theory that responds to this question reflects the absence of better empirical data on specific circumstances that might foster the development of such institutions in simple environments; we attempt here to begin filling this gap.

Previous experimental work on general equilibrium economies has focused on the double auction institution and its remarkable power to draw markets to the competitive equilibrium (Williams and Smith, 1986; Noussair et al., 1995, 1997; Lian and Plott, 1998; Williams et al., 2000; and Gjerstad, 2004).[2] In these studies people had to discover prices and specialization, but a contracting/exchange institution was defined for them exogenously, and the research program demonstrated how effective and sufficient that institution was for solving simultaneously the price-allocation discovery problem. How might any exchange institution emerge in an environment in which specialization pays but there are no exogenous institutional guidelines or third party enforcement of agreements? For example, markets for creative talent (e.g., managerial, artistic, musical, athletic) involve intensive specialization which is potentially profitable only after investment is sunk and a noisy search process is successfully navigated.[3] Formal contracts and sophisticated institutions of exchange are outgrowths of specialization as well as precursors; i.e., enforceable contract instruments emerge only after people have already discovered the forms of specialization and exchange that are expected to endure and contracts needed to encourage the expansion of such activities to new entrants and to replace agent

[1] We are indebted to Bruce Caldwell for the exact reference to Menger.
[2] Other institutions such as posted pricing and multiple unit sealed bid auctions have also been examined in single market contexts. See for example Smith (1982).
[3] Of course successful individuals eventually sign enforceable contracts, but as they are generally not legal experts, negotiated arrangements may depend significantly on faith in the integrity of other parties (that is, trust in the deal they *believe* they are getting, which may not be enforceable).

turnover. Contract terms are based on discovered practice; they are not concocted out of the void of unpracticed ignorance. As long as there are latent economic opportunities, there is value in understanding the conditions under which entrepreneurial activities are most likely to flourish.

In this experiment we establish an economic environment of production and consumption that can, if implemented socially, support specialization and exchange, but we provide the agents with no guidelines as to how to achieve this. The economy's participants must discover the ability to exchange, evolve their own procedures for trading, and simultaneously ascertain that they are comparatively advantaged in one of the two products. Hence, it is not obvious *how or if* our economies will trade, and if they trade, will approach the competitive equilibrium. Our subjects must discover exchange, specialization, competitive prices, and competitive quantities in less than an hour and a half—without instructional guidance or explicit provision of a defined message space.[4] We afford them a blank slate for natural language expressions, but they have to rely on their own sociality and inquisitiveness to try to improve their lot through any external order they create.

We observe that many people are quite adept at determining comparative advantage and coordinating their production and exchange activities with the state of the market; others are not. With no explicit trading rules, our laboratory economies exhibit a significant degree of specialization and become approximately Pareto efficient in two limited senses: Holding production decisions constant, eventually few gains from trade remain unexploited, and further, few subjects could have earned higher profits if they had unilaterally deviated from their chosen level of output. However, the ability to intuit comparative advantage, produce accordingly, and exhaust gains from trade varies across individuals and treatments, and does not translate into fully efficient specialization and exchange. Not everyone specializes to the full extent of their comparative advantage, even though full efficiency can be achieved in the economy only if everyone does so.

In our experiment, preferences are induced which favor the safety of home production relative to complete specialization at the risk of failing to find trading partners. In this respect we capture the following cultural change hypothesis: there are natural barriers to the emergence

[4] It might be thought that people presumably "know" about exchange. Actually, people learn to participate in the exchange systems of daily life, given to them in their culture, but that does not mean that they understand the work that exchange does in making specialization possible and making them better off, or easily conceive of seeking trading relationships in an unfamiliar environment in which specialization opportunities have to be discovered, and in which they receive no guidelines or instructions in what actions might be efficacious.

of trust in personal exchange where failure is costly, and success through remunerative trade and specialization can only be discovered via experience, by incurring risk, and through agreements that are entirely based on mutual consent with no explicit mechanism for enforcement. Small economies may inhibit advantageous specialization and exchange as there are fewer opportunities for likeminded matches to explore potential gains from specialization and trade. Several factors may inhibit trade in large economies, including longer searches for potential partners with compatible technology and diminished trust in cooperation given the improved outside option of each subject.[5]

Nevertheless, full specialization and efficient exchange frequently occurs bilaterally in these economies, and we do observe much efficiency improvement in a new treatment, based on our learning from the first treatments, and document some contagion in which the groping discovery of particular dyads spreads to others. Thus, many subjects do fully specialize in the productive activity in which they have a comparative advantage, and when they do so it is typically because they have entered a stable trading relationship with a specialist in the other good. However, such pairing does not necessarily give impetus to the formation of other pairs, nor are pairs typically open to the inclusion of a third party, even though pairs are never coalition-proof when at least one person in the economy is not paired with anyone else. These findings underscore the emergence of natural human experiential bias in favor of personal exchange, and the need to understand the processes through which exchange becomes less localized and bilateralized (for discussions on personal versus impersonal exchange, see North, 1990, 1991; Smith, 2003).

The paper is organized as follows. In Section 2, we describe the economic environment for our experimental economies. Section 3 outlines our design and procedures including the unstructured institution and analytical benchmarks. Our results are discussed in Section 4, and we briefly offer our concluding remarks with Section 5.

[5] On these points, see Surowiecki (2004) for a discussion on the effect of group size in coordinating economic activities.

2. The Economic Environment

Our economy consists of equal numbers of two types of agents, *odd* and *even*, who produce and consume two types of goods: *red* and *blue*.[6] Both agent types have Leontief preferences over r units of *red* and b units of *blue*:

$$U_{odd} = \min\{r, 3b\}$$

$$U_{even} = \min\{2r, b\}$$

We chose Leontief preferences in part for the relative ease in inducing the preferences for subjects. Such preferences reduce the cognitive processing load for subjects because they do not have to reference tables, functions, calculators, or indifference maps. This, we think, facilitates their focus on the task of discovering how to maximize earnings.

Agents are endowed with T units of time t to produce R units of *red* and B units of *blue*. *Odd* and *even* types also differed in their production functions. For t bounded between 0 and 10, *Odd* agents produce according to the following process:

$$R_{\text{odd}} = \frac{13}{10\sqrt{10}} t^{\frac{5}{2}} \approx 0.41 t^{\frac{5}{2}}$$

$$B_{\text{odd}} = \frac{10}{10 - \left(\frac{300\sqrt{10}}{13}\right)^{\frac{2}{5}}} (10 - t) \approx 2.25(10 - t).$$

For the *even* subjects, we have:

$$R_{\text{even}} = \frac{13}{10 - \sqrt{\frac{260}{11}}} t \approx 2.53t$$

$$B_{\text{even}} = \frac{11}{10}(10 - t)^2.$$

As will be discussed in more detail in the following section, subjects are not presented with these functions explicitly, but rather will be presented with (red, blue) output pairs for a given set of t. The production possibilities frontier for each type of agent and the autarky and competitive equilibrium benchmarks are pictured in Figure 1.[7] In autarky, it is optimal for *odd* subjects to spend 56% of their time producing red, thus producing and consuming 30 reds and 10 blues, and earning 30 cents each period. *Even* subjects optimally spend 51% of their time producing red, producing and consuming 13 reds and 26 blues, and earning 26 cents per period. In competitive equilibrium, the *odd* subjects fully specialize in the red good, producing 130

[6] These are two-agent replicator economies in the nomenclature of cooperative game theory.

[7] Of course, since there are always an equal number of the two types of agents in our economies, per capita autarky and competitive consumption are identical for all economy sizes. The uniqueness of the competitive equilibrium is proven in section 3.3.

units, while the *even* subjects fully specialize in blue, producing 110 units. The competitive price of a blue unit is 4/3 of a red unit, and at this price the *odd* subject will consume 90 red and 30 blue, while the *even* subject will consume 40 red and 80 blue. Note that competitive profits (90 cents for odd, 80 cents for even) are roughly three times greater than autarky profits.

3. Procedures and Experimental Design

3.1 Context and Procedures

Subjects are members of a *virtual village*. Each subject owns a *house* and a *field*, which he can monitor on his computer screen. He may also view the houses and fields of other members of the village.[8] Neither the type of the other subjects nor the distribution of types was known to the subjects. Preferences are induced in terms of US cents for units consumed. Depending on the treatment, the subjects are given (1) no ex ante production information (in each period they simply commit to an allocation of time, and then learn the resulting output pair), (2) an output table for a given set of proportional time allocations, or (3) a blank output table that fills in as production choices are made by themselves and by the agents of the same type (i.e., in this case, perfect recall is enabled plus subjects may learn from their counterpart's experience, as well). At the end of the instructions, the subjects were given as much time as they wished to experiment with their production functions before the session began.

Each session lasts for 40 periods, and each period is subdivided into phases *A* and *B* with *t* specified in seconds. Phase *A* is a 10-second production phase during which each subject produces red and blue goods in his field by allocating a proportion of this time to producing each good. Phase *B* is a 90-second consumption phase. Continuously and simultaneously during Phase B, subjects can use their mouse to drag and drop red and/or blue icons into their own or other houses. They are not informed that they may drag and drop icons into the houses of others, only that the payoff is based on "items that have been moved into your house." Subjects consume goods that are in their houses when the Phase *B* time runs out (thus earning cash paid at the end of the session). Subjects may communicate with each other in the village "chat room," a space where they can write messages displayed to all. Figure 2 displays a screenshot of a

[8] The purpose of the italicized words is to motivate our experimental design. Such labels were not presented to subjects to mitigate any unintended influence that these words might have on their decisions.

subject's interface. Every 7th period is a 100-second rest period, where no production or consumption takes place, but subjects may still chat with each other.

At any time the subject can adjust the slider in the top center of his screen to determine the proportion of phase *A* time to spend producing blue and red goods. The total quantity of each good produced in the phase will appear in his field and icons for each good produced will appear in the upper-left corner of his screen. These icons can be dragged and dropped into any of the houses. The subject's own house and field appear in green, while those of others are gray. In the example given in Figure 2, no units can yet be consumed, since no house registers quantities of either good. In all treatments, production and consumption quantities for each villager are public information allowing, without prompting, each to potentially learn from the (production, consumption and any trade decision) experiments of others.

In the upper right-hand corner of Figure 2 is the payoff schedule. In the top half of this schedule is a reminder of the relative value to the subject of the goods; in this case we have an *odd* subject, so he requires 1 blue for every 3 reds. In the bottom half of the schedule is a payoff calculator. In this space is calculated the number of "wasted" goods in one's house, and the number of goods of the opposite type necessary so that no quantity of either good is wasted. This calculation aid serves as an "expert" support system to facilitate a focus on thinking about the actions that might be taken.

Our parameterization was chosen to make specialization risky but potentially quite profitable. The Leontief preferences imply that complete specialization coupled with no trade will result in a payoff of 0¢ per period for the subjects, versus 26¢ and 30¢ in autarky. This circumstance may provide some robustness of our results if specialization occurs, because it is clearly not unambiguously profitable to specialize. Furthermore, the competitive equilibrium earnings of 80¢ and 90¢ per period provide a salient incentive to overcome the risk, specialize and trade. There is, however, an argument that cuts the other way. If agents with Leontief preferences produce too much of one good for their own consumption, the extra units provide an additional motivation for exchange.[9] Note, however, that the risk of specializing then failing to trade is easily subdivided: an individual in autarky is free to consume marginally fewer blue and red and attempt to trade these units to advantage, expanding incrementally if successful. Hence,

[9] These same tradeoffs are present with Cobb-Douglas preferences, albeit to differing degrees.

the form of the preferences simplify subject cognitive load without handicapping their search and discovery activity.

We chose these specific parameters for the utility and production functions so that the comparative advantage of each type was different and so that at the competitive equilibrium each type would earn similar but not identical profits. We also attempted to characterize the Leontief preferences as intuitively as possible, so that a subject either needs "1 blue for each 3 red to earn 3 cents" or "1 red for each 2 blue to earn 2 cents". We reiterate that the subjects were not in any way informed that they could exchange items with other subjects. The instructions (intentionally in the passive voice) simply stated that "When the [Phase *B*] clock expires, you earn cash based upon the number of red and blue items that have been moved to your house. To select items to be moved, *left* click on an item or click on the red or blue buttons at the top of the screen. The yellow highlighted items can be moved by dragging with the *right* mouse button."

Why not inform subjects they can trade? Adam Smith writes: "As it is the power of exchanging which gives occasion to the division of labour, so the extent of this division will always be in proportion to the extent of that power."[10] Our working hypothesis is that the ability to transfer goods and communicate freely between parties are sufficient to support specialization, as Smith famously makes it clear that the self interest is enough to lead people to promote an end not part of their intention. We expected many subjects to seek the opportunity to exchange goods without prompting, and had they been explicitly informed of the technology to trade, subjects may have limited themselves to strategies that anticipated exchange, and hence specializing. We wanted subjects to explore and choose from a broader class of strategies. We stacked the deck against specialization by not even mentioning its necessary precursor, exchange, and then observe how frequently it occurs under these disadvantageous conditions. In fact, not explicitly revealing opportunities for exchange favors the establishment of an autarky baseline, the status quo that perhaps subjects may not want to deviate from. Then, if exchange is discovered, we can observe whether subjects learn to specialize, despite the risks, by coordinating with others. In fact, this is what we observe explicitly: Prior to exchange, near-autarky prevails, and once the "power of exchanging" is discovered, specialization gradually evolves, despite any anchoring effects from beginning in an autarky framework.

[10] See his Lectures On Jurisprudence, p. 582.

3.2 Treatments

Initially, we expected that the outcomes of these economies might be influenced by variation in the number of subjects in a session. Later we added a new dimension, the extent to which each subject knows his own production function. This led to the first two series of experiments listed in the two 3×1 treatment designs (with one shared cell) shown in Table 1.[11] Row 4 led to a third series. The number of subjects in each session was 2, 4, or 8, divided into an equal number of even and odd types. We first conducted the treatments in the first three rows of column 1 with ex ante unknown production, and anticipated two effects of increasing economy size, both improving the rate of specialization and efficiency. First, we hypothesized that larger economies would more quickly discover the possibility of exchange. This turned out to be true, but not monotonically—in fact the powerful effect was fully realized in moving from 2- to 4-subject economies; discovery was actually slower in 8-subject than in 4-subject economies! Second, we hypothesized that specialists would emerge more quickly in larger economies, and that specialization cascades would frequently occur, say by imitation. This was not the case. We note here that the probability a random subject has a complementary technology to one's own is decreasing in population size, and the presence of more potential partners increases one's outside option relative to a particular exchange relationship, potentially inhibiting trust development within a given dyad.

Table 1: Experimental Design

	Production		
	Ex Ante Unknown	Perfect Recall	Ex Ante Known
2 Subjects	*Unknown2*		
4 Subjects	*Unknown4*	*Recall4*	*Known4*
8 Subjects	*Unknown8*		
8 Subjects	*Build8*		

We pre-specified only the first column and first three rows in this design, and used the learning from these experiments to explore the possible determinants of improved performance. After running the three size treatments for ex ante unknown production, we speculated that one inhibitor of specialization may have been that subjects were inadequately exploring their

[11] We also conducted three pilot sessions with classroom participants and without a rest period every 7th period. It was evident that the students could use an intermittent break to relax and reflect upon their experience.

productive capabilities. Recall that specialization is costly ex post if a subject cannot find a trading partner or specializes heavily in his comparatively disadvantageous good. If output (particularly the endpoints) were known ex ante, we thought—in keeping with conventional professional wisdom that more, apparently relevant, information is better—it would facilitate the coordination of specialization.[12] Since two of the six 2-subject sessions did not discover the ability to exchange (and one of the others did so only very late in the experiment), and the 8-subject sessions exhibited great difficulty in specializing at all, we decided the most interesting case in which to vary the information on production given to the subjects was in 4-subject sessions. If we did not observe a significant effect here, it is unlikely we would observe one in 2 or 8-subject sessions. See Figure 3 for the output tables given to subjects in the *Known4* treatment.

Anticipating the results, although the *Known4* treatment reduced the incidence of specializing in a good in which one is comparatively disadvantaged, there was not an important increase in the rate of specialization. It is plausible that ex ante known production had a mixed effect on specialization: It may have facilitated coordination, but also made explicit the potential cost of experimenting with different output levels, since subjects could now directly compute optimal autarky production. Therefore, we also chose to run a treatment with ex ante unknown production with perfect recall, in an effort to mitigate playing it safe early in the session while facilitating the coordination of production levels between subjects in the chat room. In the *Recall4* treatment, a table similar to Figure 3 was presented to subjects, but the third and fourth columns were blank. After each production phase, the appropriate line in the table was completed and maintained for the duration of the session. We note that the *Known4* treatment is highly unrealistic in a rudimentary economy yet to discover specialization and exchange. Indeed, it would be a wise husbander of goats and grower of grain when these resources were first domesticated ten millennia ago to have knowledge of the entire production possibility set. But the R*ecall4* condition is different: it merely postulates that producers might have motivation and devices for remembering outcomes when they conduct natural experiments.

What we learned from these probes is old news to experimental economists: more or better information does not assure improved performance. *Known4* and *Recall4* did not

[12] That is, if an odd-numbered subject knows he can produce 130 reds, and learns in the chat room that someone else can produce 110 blues, we conjectured it should be apparent that gains from trade exist, and this realization would prompt more specialization than when neither party necessarily knows their capabilities.

importantly improve performance over *Unknown4.* This may be because people acquire useful knowledge-how (as distinct from knowledge-that) which is retained when and if they are inspired to look for it, and thereby incorporate it into their operating knowledge. In any case we have long known that people generally do not think about decision problems the way we do as economists.

Therefore, we returned to the *Unknown* condition and introduced a new, more "evolutionary" treatment—*Build8* shown in row 4 of Table 1. We start with 8 subjects allocated to four 2-subject economies. Halfway through the experiment (20 periods), the four 2-subject economies are converted into two 4-subject economies. After half of the remaining periods (i.e., period 30), the 8 subjects are merged into a single 8-subject economy. "*Build*" turns out to be the right verb-become-noun to describe what happens to the nascent discovery process we observed in the previous independent economies, when in the new treatment we allowed the 4-subject economies to build on the knowledge-how acquired in 2-subject economies, and then allowed the 8-subject economies to accumulate further the knowledge state achieved in the groups of 4.

Subjects interacted via visually-isolated computer terminals and read self-paced instructions prior to the first period of the session. The subjects were George Mason University undergraduates randomly recruited from the university at large during the 2004-05 academic year, save the *Build8* session which were conducted in the fall of 2005. In addition to $5 for showing up on time, the average earnings in the 2-, 4- and 8-agent sessions are $13.93, $13.56, and $12.16, respectively, for a 90-minute session in this experiment.[13] The competitive equilibrium earnings for the *even* and *odd* agent types are $28.00 and $31.50, respectively, and the sum of these amounts, $59.50, represents the maximum potential profit per pair of subjects (the competitive equilibrium coincides with the solution to the imaginary egalitarian social planner's problem).

[13] After observing the results, one might ask why the experiment was limited to 90 minutes when more time might have substantially changed the convergence properties of the economies. Observations of these sessions qualitatively indicate that the experiment, the chat room in particular, is cognitively taxing. An alternative we have not pursued is to schedule longer sessions, at substantially higher payoffs to help maintain diligence and attention.

3.3 Uniqueness of Competitive Equilibrium

We have already described the competitive equilibrium (CE), but should say something about its uniqueness.[14] In consideration of CE, it suffices to consider a two-subject economy. Let p be the price of one blue unit in terms of red units. In CE, a subject in production must maximize wealth conditional on this price. Then, the intersection of his budget line and offer curve will determine his unique optimal consumption bundle. The resulting allocation is a CE if aggregate excess demand is zero; that is, the offer curves in the Edgeworth box intersect at p.

Consider the wealth function for subject $i \in \{odd, even\}$, which is equal to $R_i + pB_i$. The second derivative of this function with respect to t is strictly positive for $p > 0$ and $t \in [0,10]$; thus, the function is strictly convex on the relevant support, and its maximum is a corner. When price is sufficiently high, both subjects produce only blue, and when price is sufficiently low, both produce only red. The price at which an individual switches is equal to the ratio of his corner output. For the odd subject, this price is roughly 5.77, and for the even subject, 0.23. Thus, for a price greater than 5.77 or less than 0.23, only one type of good is produced, and since demand for both goods is strictly positive, such a price cannot be competitive. For a price between 0.23 and 5.77, the economy engages in fully specialized production by comparative advantage, and the only price that supports the intersection of the offer curves is 4/3. Of course, in the experiment such a price is not exogenously given.[15]

3.4 Broader Methodology Discussion

Our approach of providing an appropriate environment in which the subjects must discover the opportunities for exchange may also be of broader methodological import. Researchers have asked whether the departures from subgame perfection observed in certain contexts, sometimes labeled as "fairness," would obtain if a more market-oriented frame were created (see Hoffman, et al., 1994, who make such context comparisons in ultimatum games). Here we develop a way in which the importance of a market context might be tested. That is, we observe that there are numerous ways subjects can be introduced to a market (gradually-

[14] In previous version of the paper, available upon request, the details of the CE and other analytical benchmarks, like Pareto optima, the contract set, and the core, are discussed in two technical appendices: Appendix I, Definitions of Pareto optimality; and Appendix II: Observations on Waste and Realized Production Waste.

[15] Decentralized coordination on competitive prices remains an important open question in general equilibrium theory; see Crockett, Spear, and Sunder (2005) for a new approach to this issue.

immediately, endogenously-exogenously), not only the standard immediate exogenous approach, and one could test the impact of such protocols on the dynamic paths adopted in such markets. While this is not the focus of our present research, future experiments along these lines may help bridge the gap between various literatures.

It is has been 230 years since Adam Smith articulated the proposition that specialization creates wealth and that specialization is in turn supported by exchange, and yet after all this time we have no theory on the discovery process that supports exchange and specialization. Thus, we adopt a fresh approach to this important question using experimental economics. We expand the action space beyond that of a conventional laboratory experiment by incorporating a capacity for discovery for the precise purpose of perceiving relationships among facts at their nascence. Our approach is not to reduce the endogenous phenomena that we wish to observe to an elegant mechanism buried below the surface. Rather, following Johann Wolfgang von Goethe, we will "let the facts themselves speak for their theory" (Bortoft, 1996; p. 71).

Are we merely discovering something specific to this user interface? Any empirical study in the field or laboratory is inherently specific. We are setting out in this laboratory experiment to observe a simple phenomenon as a basis for understanding the initiating *process* of exchange and specialization in more complex situations. Wherever or however it originated in history, people had to learn ways of interfacing with each other in the context in which they lived and to create a social system from the inside based on natural language adapted to economic change, not an external trading institution. For example, as commerce emerged on the internet, these markets had to create new institutions to adapt to the requirements of anonymous trading. Many of these trials failed in the dotcom bubble of the 1990's. Furthermore, as is the case in our experiment much commerce today is conducted electronically between anonymous agents. While it is an important empirical question to study how economic networks evolve in face-to-face versus anonymous settings, it is abundantly clear that both environments merit careful study.[16]

[16] The naysayer may still ask, "How do you know specialization and exchange historically developed in this way?" Well, obviously we do not know or claim this. It is like in the theory of evolution. We look at the ancient archeological record and see mammals coming in after the dinosaurs. These mammals change with many similarities so that it looks like *A* followed *B* followed *C* in a evolutionary change process, but everywhere there are gaps, great missing links, and puzzles, although there is circumstantial evidence for evolution. Now someone does an experiment, takes some *a* cells passes them through a bunch of treatments alleged to represent an evolutionary process, and in one sequence the *a* cells actually evolve into *b* cells. This still does not "prove" evolutionary theory, but now we have an example and a technique and we can ask it questions. In economics you could ask the same

From North (1991) we learn of the cultural impediments in economic history to breaking out of local and limited forms of economic activity to develop new market-supported forms of specialization. Negative and even hostile public perceptions of globalization and outsourcing make it plain that impediments to trade in human thinking and biases toward the perceived safety of "home" production continue unabated.

4. Results

The chief scientific objective of this paper is to collect some basic observations on Adam Smith's first principles of specialization and exchange in an appropriate economic environment but lacking an exogenous institution for implementation. In our initial set of experiments (*Unknown*), each treatment has at least one economy (session) that never leaves autarky, and *Unknown2* and *Unknown4* each contain at least one economy that achieves or nearly achieves the competitive equilibrium. This result establishes the great variability of subject performance behavior in an unstructured institutional context—a result we had no way of anticipating in advance. Moreover, each economy has its own unique properties. Probing below this observation we find peculiar differences among the treatments that motivated a final explicating treatment, *Build8*, which we present in section 4.3.

4.1 *Unknown* Treatments

4.1.1 Discovering the Opportunity for Exchange

Recall that subjects were not informed they could drag and drop the goods they produced into the houses of others. Nevertheless, 16 of the 18 *Unknown* economies discovered the opportunity for exchange, 8 in the first period and a total of 12 by the second. As Figure 4 displays, the rate of discovery and growth was not constant across treatments; 2-subject sessions were much slower to engage in exchange, and represent the only two economies that failed to discover the possibility of exchange at all. Of the four 2-subject economies that did exchange goods, one began trading in period 2, another in period 6, and the other two in periods 18 and 19. The speed with which 4-subject economies discovered exchange was strikingly fast by

naysaying question of the theory, "How do you know that a particular market is represented by a competitive, Nash or subgame perfect equilibrium?" You don't and didn't, but that did not nor should it have prevented the theory from being developed.

comparison. A total of 5 out of 6 *Unknown4* economies moved items to other people *in the first period*. In the *Unknown8* treatment, 5 of the 6 economies moved items in the first two periods.

4.1.2 Specialization and Comparative Advantage

Across treatments, most subjects began the first several periods of a session learning to produce both goods near the autarkic quantities. By the end of the session, however, specialization increased substantially, except in the *Unknown8* economies. We define a specialist as a subject who spent at least 90% of his time producing the good in which he had a comparative advantage, which corresponds to an output (100 red, 2 blue) for odd subjects and (3 red, 89 blue) for even subjects. Figure 5 is a plot of the mean number of specialists in each treatment across periods. An average of 1-3% of the subjects in *Unknown2* and *Unknown4* specialized during the first six periods. The *Unknown8* treatment began with more specialists, an average of 16% during the first six periods. However, after the final rest period, the average proportion of specialists barely increased to 22%, whereas it increased to 50%[17] in *Unknown2* and 77% in *Unknown*.

4.1.3 Ex-post Pareto Efficiency

Under the induced Leontief preferences, some goods that were produced did not contribute to the profit of any subject in the session; these were the goods that went unconsumed or were consumed "unmatched." Let P be the total profits for the period, and W be the optimized value of the egalitarian social planner's problem that reassigns wasted goods to subjects. Then *ex-post Pareto efficiency* as a percentage of maximum potential profit is $P/(W+P)$. In Figure 6, the dashed curves represent mean ex post efficiency by treatment and period. On average, each session across treatments was 65-75% efficient in the first period and 95-100% efficient in the final period, and the improvement over time was reasonably monotonic. There was some variation across individual sessions, but most gains from trade were typically exhausted by the final periods. In fact, by the end of experiment there was usually little waste of any kind (this statement is not redundant, since wasted goods which cannot be matched in the aforementioned

[17] Note that the proportion of specialists conditional on having discovered the technology to trade in *Unknown2* is 75% after the final rest period.

social planner's problem did not contribute to ex-post Pareto inefficiency). The solid curves in Figure 6 represent the mean proportion of profit-enhancing goods to total goods produced.

4.1.4 Ex-ante Efficiency

We next address realized efficiency relative to the competitive equilibrium. In our chosen parameterization the CE allocation doubles as the optimal allocation in the egalitarian social planner's problem, so relating realized total profits to autarky and CE profits can provide a measure of social efficiency. The particular measure we adopt for a given session *s* is:

$$\Pi_{st} = \frac{\sum_{n=1}^{N} \pi_{snt} - \frac{N_s(30+26)}{2}}{\frac{N_s(90+80-30-26)}{2}},$$

where N_s is the number of subjects in the session and π_{snt} is the realized profit of subject *n* in period *t* of session *s*. Π_{st} is thus the ratio of realized to competitive profit in period *t* of session *s*, normalized so that autarky profits equal zero (recall odd subjects make 30¢ in autarky and 90¢ in CE, while even subjects make 26 and 80 cents, respectively).

Panels (a)-(c) in Figure 7 display the average efficiency over blocks of periods for each session in the *Unknown* treatments. Prior to the first rest period, the economies were 10-20% *less efficient* than autarky on average.[18] After the second rest period, mean efficiency exceeded autarky in all but two *Unknown2* sessions (in which subjects never attempted to trade goods), as many subjects who desired to trade had determined what they were comparatively good at producing. After the final rest period the *Unknown2* sessions were almost 50% efficient on average, pooling into two distinct types: Three sessions fully specialized and implemented a near-competitive allocation, and three sessions remained near autarky.

Mean efficiency in the *Unknown4* treatment was also about 50% after the final rest period, but there was much more variability between sessions. Sessions 3 and 4 each became fully specialized and were comprised of two mutually exclusive bilateral exchange partnerships. In session 4 each partnership implemented a near (pair-wise) competitive outcome. In session 3 each pair implemented terms of trade that favored the even subjects, reducing social efficiency

[18] Appendix II details the waste in these early periods, as subjects attempt to discover their comparative advantage through trial and error, fail to coordinate production decisions, and over-consume goods they end up not matching (for example, an even subject might produce 10 reds and 40 blues and immediately place them in his house, potentially wasting 20 blues in the process by not keeping them available for trade).

relative to CE, though the odd subjects still earned significantly more than autarky profit. In sessions 2, 5, and 6, one stable odd-even pair of specialists emerged by the final rest period with consequent benefit to social efficiency, while in session 1 no such pairing took place (and social efficiency stabilized near autarkic levels). In session 1 there were no specialists throughout, whereas in sessions 2, 5, and 6 the level of specialization after the final rest period was high; sessions 2 and 6 were fully specialized, and session 5 hosted 0, 2, and 4 specialists during the final five periods. Consequently, there were many unstable exchange relationships, gift-giving, and multilateral activity throughout sessions 2 and 6 (as subjects scrambled to "match" the goods they had specialized in producing without the benefit of a stable trading partner),[19] and individual profits varied substantially throughout all sessions but session 4.

It seems to be the case that exchange between identical types may have inhibited ex ante efficiency in *Unknown4*, as a stable odd-odd partnership emerged around the fourth rest period in both sessions 1 and 5.[20] In session 1 the odd-odd pair remained together throughout, and profits remained near-autarkic on average. In session 5 the pair broke up after the 36th period and an odd-even pair formed in its wake, which explains the jump in efficiency revealed in panel (b). In both sessions the even subjects tried to specialize and trade with each other after the odd-odd pair formed, but quickly gave up. The emergence of stable odd-odd pairings and the fact that 35 of 36 possible exchange relationships were actually realized (if only briefly for many) in the treatment lend credence to the "search frictions" hypothesis on what causes inefficiency in larger economies. Specifically, all subjects in these economies appear to have searched/experimented with nearly every possible exchange relationship, and occasionally stable relationships developed between "incompatible" types. The search frictions hypothesis will receive further support in the *Build8* results.

Mean ex ante efficiency in *Unknown8* was much lower than the other treatments, just over 20%. By the final rest period of this treatment, nearly every subject had settled into being a

[19] In fact, goods were exchanged at some point during each session of *Unknown4* between every possible pair of subjects but one in session 4. That is, of the six possible pairings between subjects in a session (1-2, 1-3, 1-4, 2-3, 2-4, 3-4), in 5 of 6 sessions some quantity of goods passed between each pair, and in session 4 goods passed between 5 of 6 possible pairs. Therefore, 35 of 36 possible trading relationships in *Unknown4* were actually realized, although some only briefly and for small quantities.

[20] It is actually the case that two odd subjects could completely specialize in opposite goods and still achieve profits several cents greater than autarky, whereas even subjects could not. In session 1, the two odd subjects did not meet the requirements for our definition of specialist (Subject 1's average production of reds/blues after the final rest period was 84.8/3.5, Subject 3's average production was 0/23, and their average profits during these periods were 34.8 and 46.2, respectively), but clearly they had almost completely specialized in opposite goods.

full specialist engaged in an odd-even exclusive partnership or an autarkist. In session 2, three bilateral partnerships of specialists emerged and pushed mean profits to about 60%. In both sessions 1 and 5, one such partnership emerged and pushed mean profits to 20%. These ten specialists earned profits much closer to the competitive equilibrium than autarky, while the other subjects (almost 80% of the total) remained near autarky. Similar to *Unknown4*, each subject typically sampled exchange with every other subject. This fact is surprising, as there were 28 possible pairs of subjects in each session. In one session all pairs were sampled, in three sessions 27 of 28 pairs were sampled, and in two sessions 25 of 28 pairs were sampled. Unlike sessions 2 and 6 of *Unknown4*, specialization in *Unknown8* was only initiated and maintained in long-term partnerships. Individuals who could not find suitable partners generally settled into autarky, whereas subjects in *Unknown4* were much more likely to continue to specialize and seek gains from exchange.

Thus, the problem appears to be about finding and maintaining a suitable trading partner, and individuals in 8-subject economies are quicker to give up the search. There are at least two plausible reasons why coordination could be more difficult in larger economies. First, the proportion of subjects with compatible technologies gets smaller as N gets larger; this proportion is equal to $(N/2)/(N-1)$. In an *Unknown2* economy, one's (potential) partner is always technologically compatible (although each person still has to discover the good in which she has a comparative advantage). In an *Unknown4* economy, 2/3 of the other subjects are compatible, while only 4/7 are compatible in the *Unknown8* economies. Some subjects, by trying to coordinate production and exchange with a subject of the same type, or by choosing to specialize in the wrong good or at the wrong time, were simply unable to find and coordinate activities with a compatible partner in the village. A second inhibitor of exchange may have been that the outside option of each subject increases in the number of subjects. In a larger economy, a subject may have some expectation that he can find another "partner" in later periods and other subjects are potentially aware of this possible expectation, though developing such a relationship may take time. The fact that nearly every potential partnership was sampled in *Unknown4* and *Unknown8* can be interpreted to lend support to either impediment, while the formation of two stable odd-odd pairs of specialists in *Unknown4* directly supports the former. We develop the *Build8* treatment to isolate the effect of trading partner search in the evolution of exchange and specialization.

4.2 *Known4* and *Recall4* Treatments

The conventional wisdom in economics is that more information is better in terms of coordinating economic activity. With the above results in hand, we decided to explore the impact of information on the production capabilities for the 4-subject economies. If we did not observe a significant effect here, it is unlikely we would observe one in 2 or 8-subject sessions. We conducted 7 sessions in the *Known4* treatment and 6 in *Recall4*,[21] and find that neither treatment had any noticeable impact on the observations above for *Unknown4*. As is apparent from Figures 4-7, these economies discover and adapt exchange in a pattern similar to *Unknown4*.

From Figure 5 we observe that the proportion of *Recall4* and *Known4* specialists was quite similar to the *Unknown4* treatment through the fifth rest period. For example, the average proportion of specialists between the fourth and fifth rest periods is roughly 60% in *Unknown4*, 58% in *Recall4*, and 56% in *Known4*. If anything, sessions in these latter treatments tended to be a bit slower to specialize. However, there was a small drop in specialization after the final rest period in *Recall4* to 55%, whereas *Unknown4* and *Known4* continued to become increasingly specialized, to 77% and 69%, respectively. Even though the *Known4* treatment would presumably reduce the incidence of specializing in a good in which one is comparatively disadvantaged, there was not an important increase in the rate of specialization. It is plausible that ex ante known production had a mixed effect on specialization: It may have facilitated coordination, but also made explicit the potential cost of experimenting with different output levels, since subjects could now directly compute optimal autarky production.

As panels (d) and (e) in Figure 7 display, these economies were also 10-20% *less efficient* than autarky on average before the first rest period, despite the fact that autarky production is relatively easy to determine from the subjects' production tables. The patterns of exchange that emerged by the final rest period are similar to the patterns in *Unknown4*. Three of 7 sessions in *Known4* and 2 of 6 sessions of *Recall4* fully specialized and implemented mutually exclusive bilateral partnerships which traded reasonably near the competitive equilibrium. In addition, in 3 of 7 sessions in *Known4* and 2 of 6 sessions in *Recall4*, one fully specialized opposite-type high-

[21] In one session of *Known4*, a power cord was tripped in the lab, resulting in some data loss. We lost all chat and exchange data, and some production and consumption data. In particular, we collected consumption data through period 29, and production data through period 33. Therefore, we ran an additional session so that we could include 6 complete sessions in the treatment.

volume pair emerged. In these sessions average ex ante efficiency was 25-50% following the final rest period. In the other three sessions, no high volume trade occurs, and average profits converged to autarkic profits. Similar to *Unknown4*, of the 72 possible pairs that could have formed across these sessions,[22] 71 actually realized exchange (only one pair of subjects in one session of Known4 never had goods pass between them). Also, in three of the sessions (one in *Known4*, two in *Recall4*) there was substantial trade between an odd-odd pair for at least part of the experiment, and in two of these sessions no high-volume opposite-type partnerships formed.

4.3 Summary of Observations

We find that a small majority of subjects either settle into autarky or specialize in their comparative advantage immediately. The rest typically do so over the course of time, and most substantial and sustained trade occurs between appropriately specialized subjects of the opposite type. None of the 2-, 4- and 8-person economies rise above the autarky equilibrium in periods 1-6, and most continue this performance into periods 7-12 (see Figure 7). In 2-person economies, three pairs discover and achieve the competitive equilibrium by the 40th period; it took 28 periods for the three pairs to establish their like-minded willingness to explore exchange and specialization, and step out of their autarky homes; and having done so, they almost immediately find the competitive equilibrium. The other three pairs discover the autarky equilibrium by the 20th period and remain there, two of the pairs never having attempted to exchange goods (see panel (a) of Figure 7).

With 4- and 8-subject economies, most ex ante efficiency in excess of autarky can be attributed to stable high-volume bilateral pairings between odd and even subjects. For the *Unknown4*, *Known4*, and *Recall4* treatments, the proportion of subjects who are members of such relationships after the final rest period is .58, .64, and .50, respectively, whereas in *Known8* this proportion drops to .21. Thus conditional on having discovered the technology to exchange, the development of such partnerships was monotonically decreasing in population. While all subjects in the 4- and 8-subject economies were party to exchange and nearly all potential pairs (however briefly) exchanged goods, the number of active pairs was substantially reduced by the third rest period in *Unknown8* relative to all 4 subject treatments. It appears as though subjects in *Unknown8* much more quickly resigned themselves to autarky than in the smaller economies.

[22] Excluding session3 of *Known4* for which we have no data, as was explained in a previous footnote.

Providing more 'recall' or complete information on production possibilities did not in any substantial way alter these observations. If anything can be said, it may appear that complete information created a mental framework that hindered subjects from leaving autarky.

It should also be noted here that in 5 of 19 4-subject sessions, an odd-odd stable pair emerged for at least 5 periods. In one of these sessions the pair eventually split after the final rest period and opposite-type exchange began to emerge. In two others one of the odd types also traded substantially with an even subject, and in the other two sessions no substantial sustained opposite-type trade ever occurred. There is a strong negative correlation between social efficiency and the occurrence of these stable odd-odd pairs, which supports the notion that the search for compatibility was a significant drag on efficiency.

We observe three steps to achieving the competitive equilibrium in these exchange and production economies: (1) arriving at the idea to trade, which may require "mind reading" (inferring thoughts from words and actions) and imitation (limited to 4- and 8-person economies), (2) finding a suitably endowed trading partner with whom one can benefit from the power of exchanging through specialization, and (3) building the relationship by increased specialization over time. In the larger economies imitation can hasten the discovery of exchange, but (2) and (3) can conflict and increase waste: effort spent searching for a partner match reduces effort invested in developing the exchange-specialization relationship with any one partner.

4.4 *Build8,* An Explicating Treatment

The following excerpt from a transcript demonstrates how quickly, upon achieving step 1, two people alone in session 6 of the *Unknown2* treatment can complete the next two steps and achieve complete specialization:

***** Period 18-B *****

2: wonder if u can give me objects
1: oh yeah..
2: heyyy
2: i make blues faster
2: what color do u make?
2: faster
1: red
2: lol[23]
2: ok
1: LOL
2: so ill make all blues

[23] The shorthand "lol" stands for "laugh out loud".

2: and u make all reds
1: then drop them to each other's houses?
2: yea
2: do it
1: ok
1: 100% red
2: 100% blue
[The subjects achieve complete specialization in the next period.]

The tone in the above excerpt clearly indicates that the emergence of a natural propensity to exchange is indeed personal and social.[24] In this section we further explore steps (2) and (3) with an additional treatment that gradually builds eight-person economies. In particular, we begin each session with four two-person economies, and after half of the periods we merge the pairs into two four-person economies for half of the remaining periods.[25] For the final quarter of the experiment, we then merge the two four-person groups into one group of eight agents. With this design we reduce the transaction costs of finding a suitable trading partner. Moreover, by gradually growing the size of the economy, we introduce new potential trading partners who, having had the opportunity to discover their own comparative advantage and are in the process of gradually increasing the rate of specialization, could conceivably compete with a new potential trading partner. Lastly, if individuals have not discovered trade, this allows others to emulate the exchange and specialization innovations of others.

In the *Build8* treatment, the eight subjects were paired for the first 20 periods as follows: Person 1 with 2, Person 3 with 4, Person 5 with 6, and Person 7 with 8. In period 21, a rest period, Persons 3 and 4 joined Persons 1 and 2, and Persons 7 and 8 join Persons 5 and 6. By "joined" we mean that their fields and houses all appeared on the screen and all were able to

[24] And it is frequently conveyed explicitly as such:

Session 4, *Unknown2*
***** Period 17-B *****
Person 2: can i put them things in your house?
Person 1: i dont think so
1: oh thats ur house
***** Period 18-B *****
2: you can put them in each others house
1: oh ok
2: do you know which one you make faster
***** Period 19-B *****
2: im trying to think how maybe *we could help each other* [italics added]

[25] Each subject was instructed before his session began that a total of eight subjects were participating in his session, but was given no additional information about village size or growth. Thus, in periods 21 and 31 new house and field icons will appear on his screen and new voices will be heard in the chat room, but these additions were otherwise completely unannounced.

communicate with each other in the chat room. Finally, in period 31, all eight subjects were combined to form a single community as in the *Unknown8* treatment.

Session 6 exemplifies the dynamics at work. Figure 8 reports the ex ante efficiency of session 6 of the *Build8* treatment by pairs of individuals. Persons 5 and 6 early on discovered exchange and began to notably specialize in periods 8 through 13. Four periods after Persons 7 and 8 joined them, this new pair imitated Persons 5 and 6 and went from the autarky straight to the pair-wise competitive equilibrium. When Persons 1 through 4 joined them and observed the wealth of these four individuals working in pairs, they joined them at the competitive outcome. At the conclusion of the session, this group of 8 subjects was 100% efficient.[26]

Exceptional loyalty to initial partners[27] and high specialization adoption rates shortly after the exogenous introduction of specialized pairs to a group of non-specialists are the hallmark features of *Build8*. Subjects assured each other of their relationship when the strangers' houses and fields appeared. The transcript from session 3 in period 31 clearly demonstrates this:

***** Period 31-A *****
{Room B} Person 1: ok
{A}1: ahhhhhhhhhhhhhhh
{A}2: holy crap....

***** Period 31-B *****
{A}8: yikes
{A}2: stay the same
{A}1: yea they can
{B}4: Person 3 jsut do what I said
{A}1: yea same ppl
{A}8: 7.....stay the same
{A}7: aye
{A}7: whoa, the top four are producing a lot more
{B}4: Person 3 good job
{B}3: haha looks like we're doing the best 1, 2, 4
{A}6: anyone have extra red?
{A}2: we're hott like that
{A}7: what are your exchange rates?
{B}4: yeah
{A}1: yeaaaa
{A}2: hah
{A}2: 100%

Successfully specialized subjects frequently coached non-specialists on how to coordinate their activities with each other. Another observation likely related to these bilateral bonds is that 9 of

[27] Two-thirds of the subjects in *Build8* were able to specialize and earn at least double autarky profits by the end of the treatment, and each of them was engaged in strictly "monogamous" trade with their original partner.

the 16 pairs of specialists in the *Build8* (56%) converged to the **exact** pair-wise competitive equilibrium by the end of the experiment, and many others were reasonably close. The terms of trade that evolved are more similar to terms between specialists in *Unknown2* than specialists in the 4-subject treatments or *Unknown8*.

The main thrust of the differences between *Build8* and *Unknown8* is reported in panels (c) and (f) in Figure 7. Our main finding is that the trajectories of ex ante efficiency in these two treatments are quite different. Three of the six economies in the *Build8* treatment are on nearly linear paths to the competitive outcome from the beginning of the experiment. Two others emerge from autarky shortly after all eight people merge, and one remains in autarky. This stands in stark contrast to the *Unknown8* treatment in which only one session approaches 60% efficiency by the end of the experiment and the five other sessions were all 20% efficient at best. Comparing the average efficiency for the six sessions in each treatment, these differences are significant using a Wilcoxon rank sum test for periods 36-40 and also for periods 29-34 ($W = 51$, $n = m = 6$, p-values = 0.0325). Table 3 reports similar Wilcoxon tests for the other regimes of periods between rest periods. It is interesting to note that three of the first four regimes are not significantly different save regime 2, periods 8-13 ($W = 51$, $n = m = 6$, p-values = 0.0325)). This suggests that this nascent personal exchange among pairs of subjects in periods 8-13 creates the early initial conditions for discovering exchange and specialization. In sum, the inference from a comparison of the *Build8* and *Unknown8* treatments is that with the same outside options for exchange by the end of the experiment, the matching costs and personal nature of the exchange are key components for exploiting the wealth creation opportunities from exchange and specialization.[28]

Table 3. Wilcoxon Rank Sum Tests of Efficiency

H_a: $\mu_{Build8} > \mu_{Unknown8}$

Regime: Periods	W	p-value
1: 1-6	41	0.4091
2: 8-13	51	0.0325
3: 15-20	41	0.4091
4: 22-27	47	0.1201
5: 29-34	51	0.0325
6: 36-40	51	0.0325

N.B. $n = m = 6$ for tests.

[28] Before one quickly dismisses the *Build8* results as unsurprising, recall the unanswered questions raised by the non-monotonic results for the 2-, 4-, and 8-subject economies in the *Unknown* treatment and furthermore how this

5. Discussion and Conclusion

In this paper we report an experiment designed to examine the performance of a production-consumption environment that can support exchange and specialization, but the subjects receive no institutional guidelines for enabling them to achieve the benefits that such an economy can generate. Individually such benefits are over triple the payoffs that would be earned from autarky based on home production and consumption. Our subjects must first discover that exchange is a feasible activity, enabling value to be created by supporting specialization, and then to develop the limits to that discovery; to achieve this, they must ascertain their particular circumstances and unknown possibilities for production. As the findings in our larger economies (in *Unknown4* and in *Build8*) indicate, exchange in this setting is characterized by a growing number of bilateral trades over time that are highly personal and social, i.e., not by the multilateral sort of exchange usually associated with markets organized by institutional rules specified by the experimenter. Thus, none of our economies "invent" multilateral "double auction" trading through, say, an extended order of bilateral negotiation to explore and facilitate pairing. Why? Is it "unnatural" to thereby depersonalize the exchange-specialization relationship, and perhaps disrupt reputation formation, as in finding a way that "maybe we could help each other?" Is the "double auction" an example of a constructivist formal institution, the product of entrepreneurial "invention" which was then selected wherever it was found to have fitness advantages? Is it simply that necessity is the mother of invention and our environment demands only a bilateral structure to solve the optimization problem?

Now that our subjects have taught us the work that it can accomplish, an alternative to the *Build8* treatment is to allow subjects in the initial 2-subject economies to choose at any of defined intervals (perhaps after each block of six periods) to join a 4-subject economy provided that there are at least four subjects voluntarily choosing that option. This more "realistically" makes group formation voluntary and endogenous, rather than exogenously imposed by the experimenter. Moreover, the potential diversity in the ensuing dynamic, and the effect of this treatment on economic growth might yield insights.

Our experiment is but a first step in understanding the dynamics of human behavior in personal social exchange and its extension to much more abstract institutions of impersonal

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observation stands in contrast to the standard intuition that larger economies are more efficient economies. The key question is by what process of growth and change do large economies grow into more efficient economies.

market exchange. This central question is often implicitly posed or thought of as one of cooperative versus non-cooperative behavior or personal *versus* impersonal exchange, when, to the contrary, the point is to understand the terms of the *trade-off* between engaging in personal and impersonal exchange. Future research can build upon this discovery-based framework to vary available options in an incremental way, thereby shedding new light on the means by which exchange and specialization create wealth.

References

Buchan, J. C*rowded with Genius.* New York: Harper Collins, 1998.

Crockett, S., "Learning Competitive Equilibrium in Experimental Exchange Economies," Working Paper, revised February 2005.

Crockett, S., S. Spear, and S. Sunder, "Learning Competitive Equilibrium," Working Paper, revised June 2005.

Ferguson, A. *An Essay on the History of Civil Society.* London: A. Millar and T. Caddel, third edition, 1767/1773.

Gjerstad, S., "Market Dynamics in Edgeworth Exchange," Working Paper, 2004.

Hayek, F. *The Fatal Conceit.* Chicago: The University of Chicago Press, 1988.

Hoffman, E., K. McCabe, K. Shachat, and V. Smith, "Preferences, Property Rights, and Anonymity in Bargaining Games," *Games and Economic Behavior* 7, 346-380, 1994.

Lian, P, and C. Plott, "General Equilibrium, Markets, Macroeconomics and Money in a Laboratory Experimental Environment," *Economic Theory* 12(1), 21-75, 1998.

Menger, C., *Investigations into the Method of the Social Sciences with Special Reference to Economics*, ed. Louis Schneider, translated by Francis Nock. New York: NYU Press, 1985.

North, D., "Institutions," *Journal of Economic Perspectives*, 5(1), 97-112, 1991.

North, D. Institutions, Institutional Change and Economic Performance, Cambridge, MA: Cambridge University Press, 1990.

Noussair, C., C. Plott, and R. Riezman, "An Experimental Investigation of the Patterns of International Trade," *American Economic Review*, 85(3), 462-491, 1995.

Noussair, C., C. Plott, and R. Riezman, "The Principles of Exchange Rate Determination in an International Finance Experiment," *Journal of Political Economy* 105 (4), 822-861, 1997.

Smith, A., Lectures On Jurisprudence, ed. R. L. Meek, D. D. Raphael and P. G. Stein, vol. V of the Glasgow Edition of the Works and Correspondence of Adam Smith (Indianapolis: Liberty Fund, 1982).

Smith, V. L., "Microeconomic Systems as an Experimental Science," *American Economic Review*, 72(5), 923-955, 1982.

Smith, V. L., "Constructivist and Ecological Rationality in Economics," *American Economic Review*, 93(3), 465-508, 2003.

Surowiecki, J., The Wisdom of Crowds, New York: DoubleDay, 2004.

Williams, A. and V. L. Smith, "Simultaneous Trading in Two Competitive Markets" Manuscript, Indiana University Department of Economics, Bloomington, Indiana, 1986.

Williams, A., V. L. Smith, J. O. Ledyard and S. Gjerstad, Concurrent Trading in Two Experimental Markets with Demand Interdependence." *Journal of Economic Theory*, 16, 511-528, 2000.

Figure 1. Production Possibilities Frontier

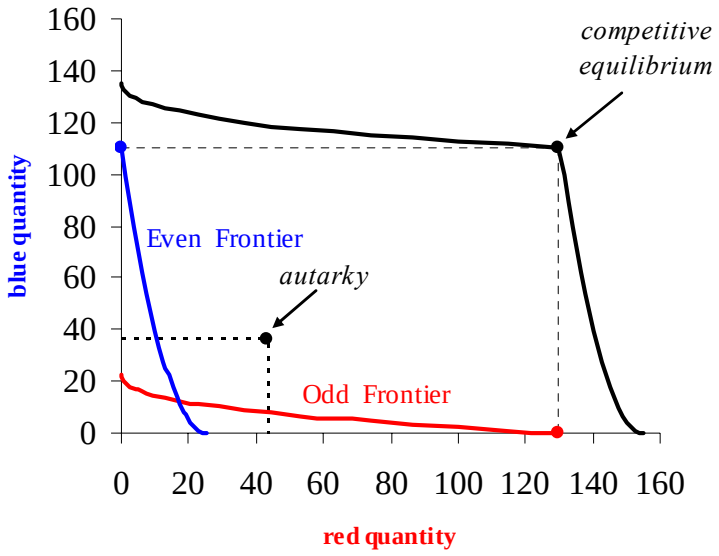


Figure 2. Example of a Subject Interface (*Unknown8* Treatment)

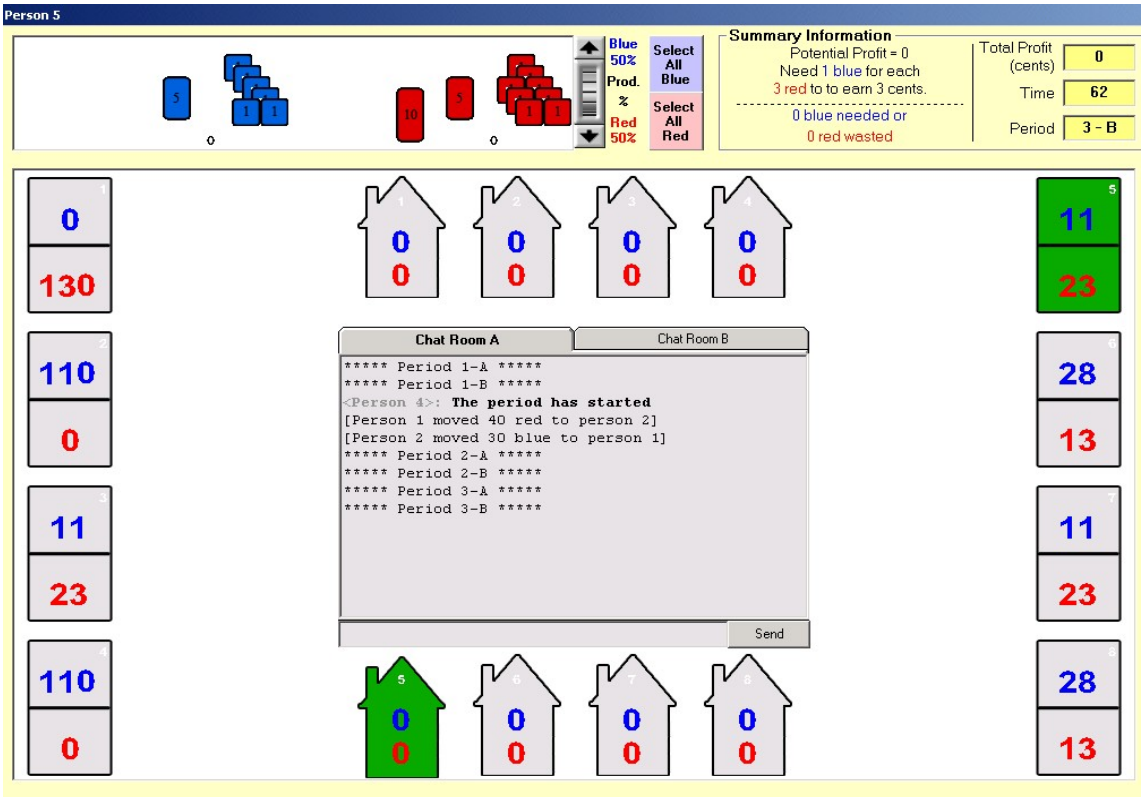


Figure 3. Subject Output Tables (*Odd* subjects first, *Even* second)

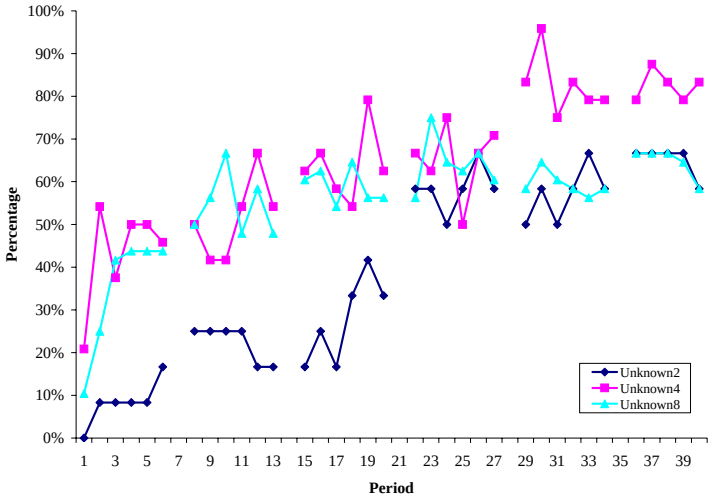
Production Table

Production			
Blue %	Red %	Blue	Red
0%	100%	0	130
5%	95%	1	114
10%	90%	2	100
15%	85%	3	87
20%	80%	5	74
25%	75%	6	63
30%	70%	7	53
35%	65%	8	44
40%	60%	9	36
45%	55%	10	29
50%	50%	11	23
55%	45%	12	18
60%	40%	14	13
65%	35%	15	9
70%	30%	16	6
75%	25%	17	4
80%	20%	18	2
85%	15%	19	1
90%	10%	20	0
95%	5%	21	0
100%	0%	23	0

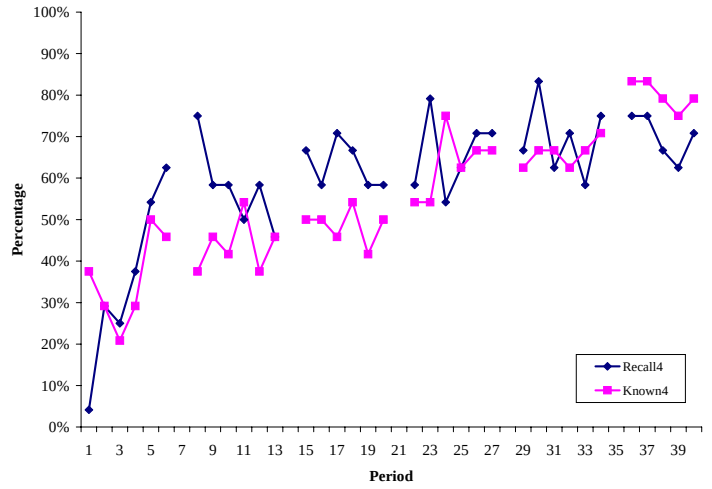
Production Table

Production			
Blue %	Red %	Blue	Red
0%	100%	0	25
5%	95%	0	24
10%	90%	1	23
15%	85%	2	22
20%	80%	4	20
25%	75%	7	19
30%	70%	10	18
35%	65%	13	16
40%	60%	18	15
45%	55%	22	14
50%	50%	28	13
55%	45%	33	11
60%	40%	40	10
65%	35%	46	9
70%	30%	54	8
75%	25%	62	6
80%	20%	70	5
85%	15%	79	4
90%	10%	89	3
95%	5%	99	1
100%	0%	110	0

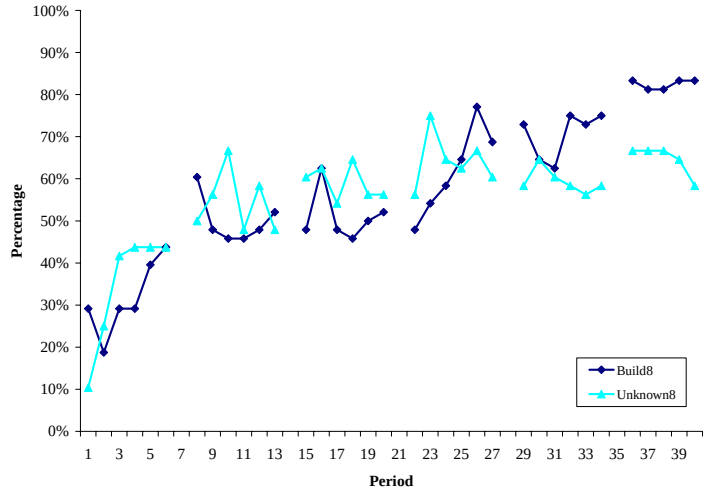
Figure 4. Mean percentage of Subjects by Treatment Who Move an Item to Another Person



Panel (a). *Unknown* Treatment



Panel (b). *Known and Recall* Treatments



Panel (c). *Build* Treatment

Figure 5: Proportion of Specialists

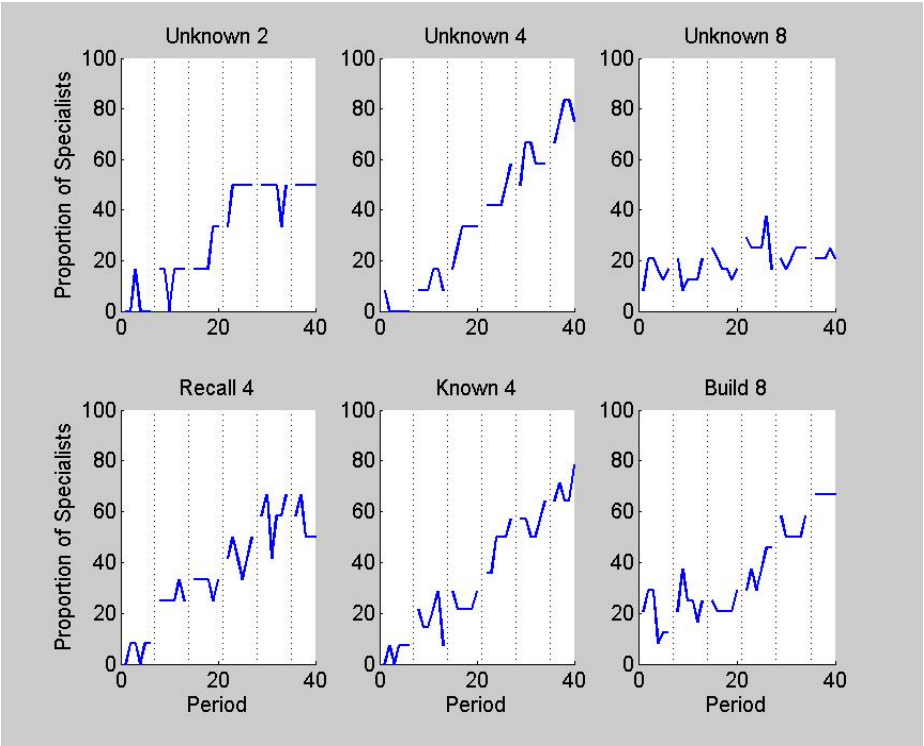


Figure 6: Ex Post Efficiency

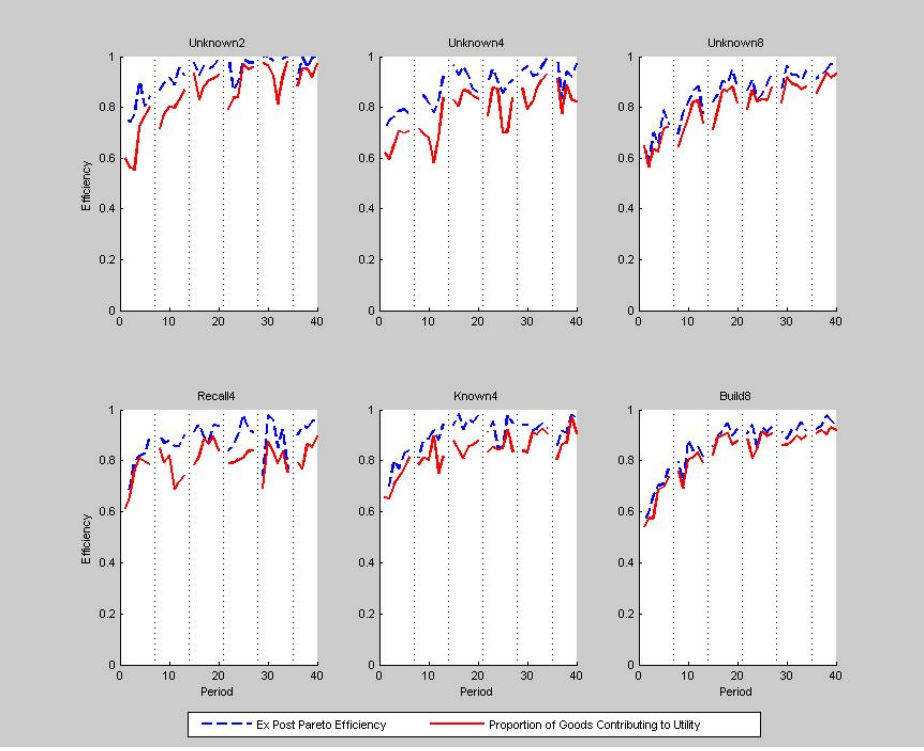
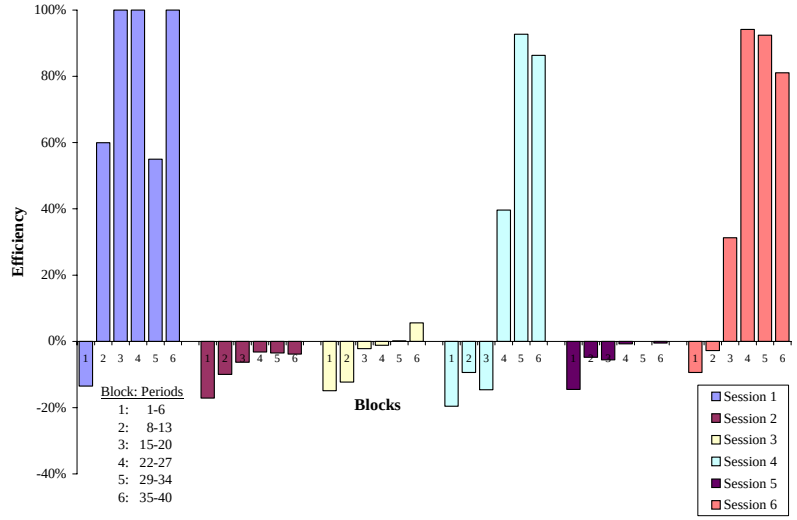
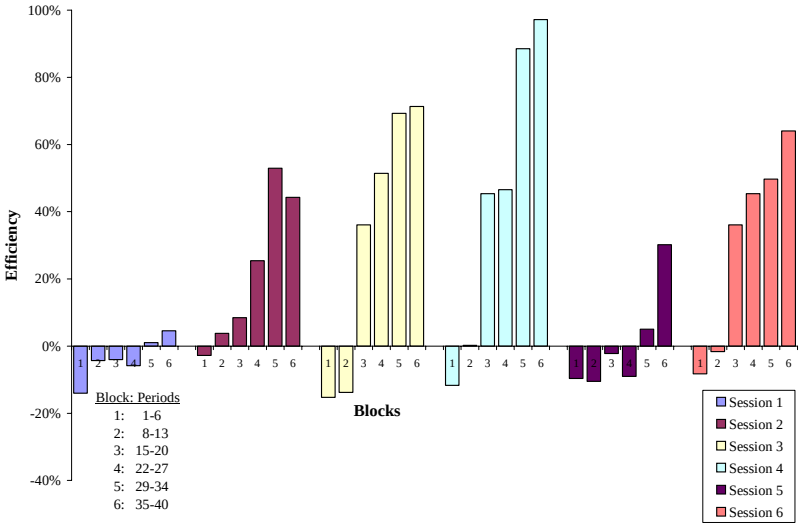


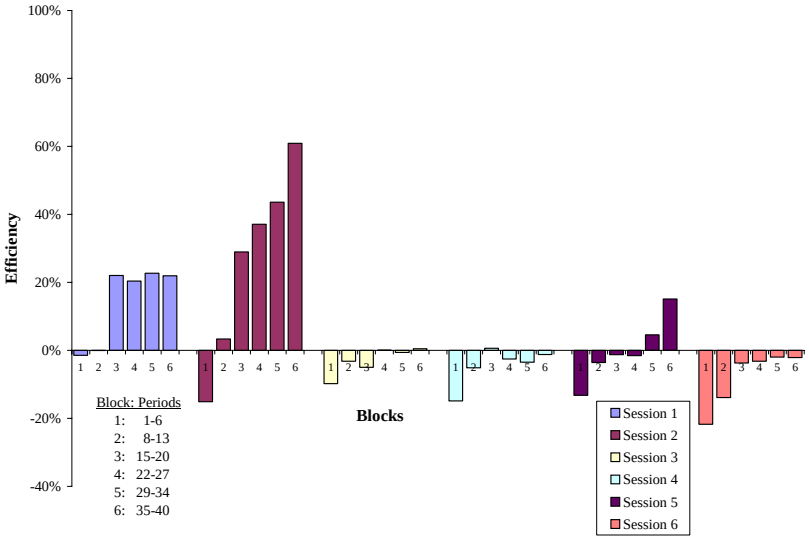
Figure 7. Ex Ante Efficiency



Panel (a). *Unknown2* Treatment

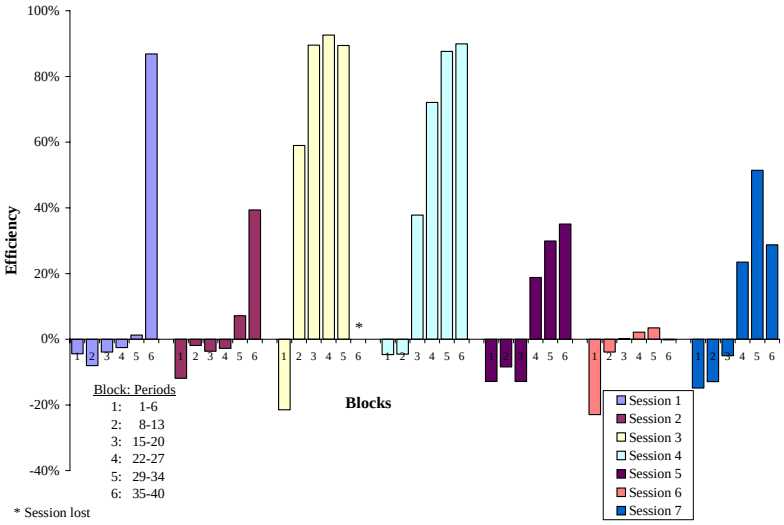


Panel (b). *Unknown4* Treatment

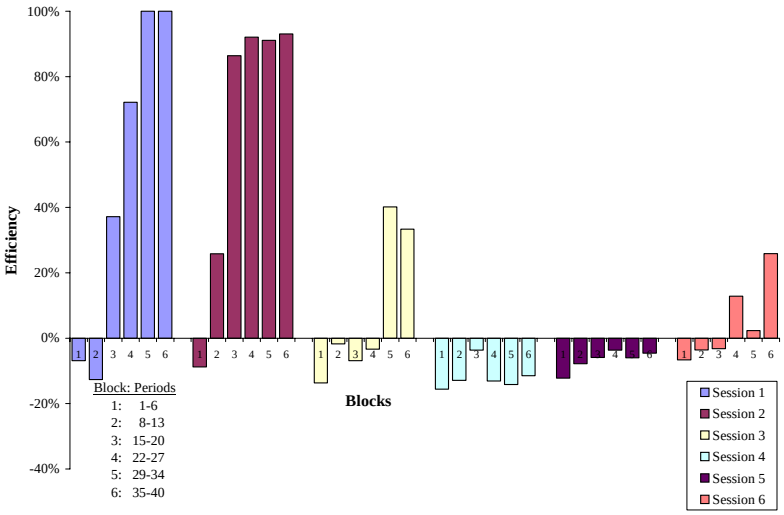


Panel (c). *Unknown8* Treatment

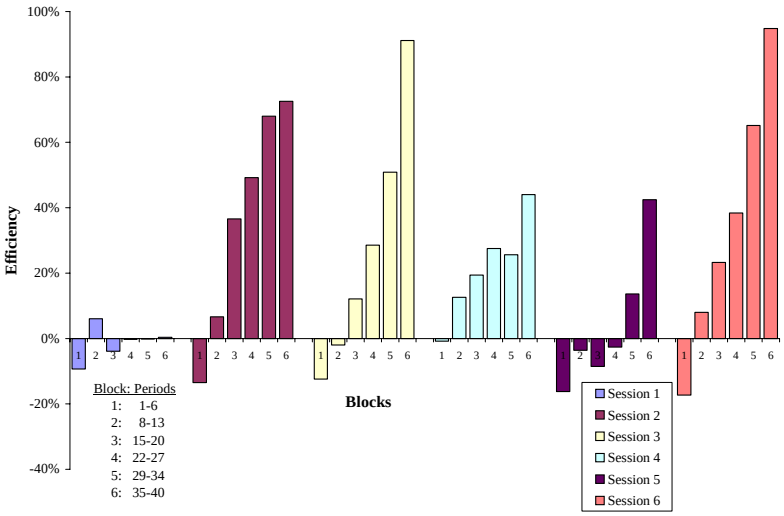
Figure 7. Ex Ante Efficiency



Panel (d). *Known4* Treatment



Panel (e). *Recall4* Treatment



Panel (f). *Build8* Treatment

Figure 8. Efficiency by Subject Pairs for *Build8* Session 6