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A note on the essentiality of money under limited memory

Thomas Wiseman[1]

Department of Economics, The University of Texas at Austin, United States

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ABSTRACT

I use a simplified version of Trejos and Wright's (1995) random matching environment to make a point about when fiat money is *essential* – that is, when the set of equilibrium outcomes is strictly larger with money than without. Under two natural forms of limited memory, money becomes essential when small, idiosyncratic shocks to production costs are introduced. Monetary equilibria approach full efficiency in the limit as agents become patient, while without money no trade is possible in equilibrium for any discount factor.

1. Introduction

Kocherlakota (1998) gives conditions under which "money is equivalent to a primitive form of memory," in the sense that fiat money can substitute in economic environments for agents' knowledge of the histories of other agents. That paper examines (among other environments) a simplified version of Trejos and Wright's (1995) random matching setting, where one agent can produce a unit of a valuable good for his partner at a small cost. It shows that any equilibrium outcome in an environment with money is also an equilibrium outcome in that environment with memory, where memory is defined as full information about the past behavior of one's current partners, their previous partners, their previous partners' previous partners, and so on. Thus, some limitation on memory or monitoring is necessary for money to be *essential* – that is, for introducing money to expand the set of equilibrium outcomes. (See also Wallace, 2011.) Araujo and Camargo (2015) and Wallace (2014) argue that even very limited monitoring makes money inessential, because folk theorems apply very broadly. In this paper, I use a simple random-matching framework to show that in two natural limited-memory environments, money is in fact essential if agents' costs exhibit any degree of heterogeneity (as they would in many economic settings), because it is robust to cost shocks in a way that folk-theorem type strategies are not.

In the model, there is a continuum of infinitely-lived agents with a common rate of time discounting. There are multiple types of perishable goods. Each agent produces one type of good and consumes a different type, so there is scope for beneficial trade. In each period, agents are randomly matched in pairs. A match is *aligned* if one member of the pair can produce the good that the other member likes to consume. (Matches with a double coincidence of wants are ruled out

E-mail address: wiseman@austin.utexas.edu.

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by assumption, so trade cannot immediately benefit both match partners.) An agent's cost of producing is subject to very small, i.i.d. shocks. Before the matches in a period are realized, agents would like to commit to produce in any aligned match, because the benefit of consumption always exceeds the cost, but ex post the producer prefers not to incur the cost. Thus, in a one-shot interaction, no good will be produced. Similarly, because the members of a pair will be matched together again in the future with probability zero, no production also will be the outcome of every matching if agents cannot observe the history of past interactions of their current partners (the case of no memory).

Consider two natural forms of limited memory. In the first, when agents are matched, each observes the full history of his partner's interactions but not the outcomes of his partner's previous partners' other past interactions, or of their previous partners', etc. (Consumer credit histories and online shopping reviews are broadly consistent with those features.) The second setting is bounded memory, where agents observe all higher orders of information (the actions of partners' previous partners, and so on), but only for the most recent K periods, for some finite K. (Liu and Skrzypacz, 2014, argue that informal or fast-growing markets often exhibit bounded memory.) With either form of limited memory, if agents are patient enough, then in the absence of cost shocks there is an efficient sequential equilibrium, where production occurs in every period in every aligned match. An agent chooses to produce today because her future partners will produce for her with higher likelihood if she has produced in the past. Those equilibria, however, rely on mixed strategies as off-equilibrium punishments: the future partners must be indifferent between producing or not. Introducing arbitrarily small cost shocks breaks that indifference, and the equilibrium collapses. The only remaining equilibrium outcome is completely *in*efficient: no one ever produces.

In contrast, the presence of indivisible, tradeable units of money can make production possible, at least some of time: the producer produces in exchange for a unit of money. Roughly, the fact that the consumer has money to pay serves as evidence that he produced (and therefore was paid) in the past. Agents can hold any amount of money. If the money stock increases optimally with the agents' patience, then in the limit full efficiency can be approached. These monetary equilibria, unlike the efficient equilibria with limited memory, are robust to the introduction of cost shocks.

The reason that money outperforms memory, roughly, is that requiring physical units of money to verify good behavior prevents a particular deviation. In order to sustain trade, an agent i who refuses to produce when it is his turn must be punished: a future partner j must be willing not to produce when matched with i. However, giving agent j that incentive is delicate. Because agent j's future partners will not see agent i's history, they cannot tell whether agent j's refusal to produce was an on-equilibrium punishment of agent i (in which case agent j should not be punished) or just a deviation by agent j (in which case agent j should be punished). Thus, agent j expects the same continuation payoff after refusing to produce *regardless* of whether or not agent i deserves punishment – to be willing to punish the guilty and reward the innocent, agent j must be indifferent. That indifference breaks down in the presence of cost shocks, as described in more detail in Section 4.1. In the environment with money, the analogous situation is that a producer matched with a consumer who has no money must "punish" that consumer by not producing. In this case, even if the producer would strictly prefer to produce and get a unit of money in exchange, that deviation is not possible, because the consumer has no money to give. Indifference, then, is not required, and the monetary equilibrium is robust to small cost shocks.

It is important to note that "memory" here, as in Kocherlakota (1998), refers to a verifiable record that agents can observe, and not to what an individual agent can remember about his own past. For example, in the bounded memory case, an agent recalls all of his previous transactions (as well as all the information that he had about past partners' histories), but he is not able to credibly convey that information to his current partner. In game theoretic terms, the limits on "memory" apply to monitoring and not to players' recall.[2]

The organization of the rest of the paper is as follows: Section 2 compares the assumptions and results here to others in the literature. Section 3 presents the model formally, and Section 4 contains the main results. Section 5 concludes.

2. Comparison with other models

The focus of many papers on the microfoundations of money (for example, Kiyotaki and Wright, 1991, 1993; Trejos and Wright, 1995, and Araujo, 2004) is to explore how and how much fiat money can improve efficiency relative to the case of no money and no memory. Kocherlakota (1998), on the other hand, asks how fiat money performs relative to the case where an agent has full information about his partners' history, their partners' histories, and so on. As was described in Section 1, he finds that money cannot do better than this full memory. Araujo and Camargo (2015) consider an environment with much more limited memory. They show that patient players can achieve the first-best outcome (and thus that money is inessential) even if an agent observes only the most recent role and action of his current partner. Neither paper allows for cost shocks, and the analysis in Section 4 will show that Araujo and Camargo's (2015) result is not robust to including them.[3]

Following Kocherlakota (1998), a number of papers have examined how different forms of memory (that is, record keeping) influence the essentiality of money. Kocherlakota and Wallace (1998) study an environment where all agents' actions are publicly observed, but with a stochastic lag. They find that for a fixed discount factor, money can improve outcomes if the expected lag is long enough. However, for any fixed expected lag, money is inessential in the limit as

[2] I thank a referee for emphasizing this point.

[3] Araujo and Camargo (2015) show that their result *is* robust to introducing shocks to *consumers'* preferences. That finding, which also applies to the model in this paper, holds because in the equilibrium supporting the efficient outcome, consumers play a strict best response at all histories. Only producers are required to mix.