Intermediation, Search, and Transfer Augmented Double Auctions*

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Abstract

This note develops a double auction that, subject to incentive compatibility and individual rationality constraints, is optimal for a broker who enables trade between one buyer and one seller with values drawn independently from uniform distributions. Like in a standard double auction, the transaction price is the mean of the buyer's and the seller's bid, provided the former exceeds the latter. On top of that, the buyer and the seller pay fixed transfers to the broker if transaction takes place. A double auction that induces ex post efficient trade is constructed in a similar vein. The note then shows that a bid and ask price setting market maker who trades with a continuum of buyers and sellers with values drawn from the uniform and who faces competition from a random matching market nets the same profit when the terms of trade in the random matching market are determined by (i) Nash bargaining, (ii) take-it-or-leave-it offers, or (iii) a broker optimal double auction. In contrast, when the standard double auction is employed in the random matching market, the market maker is strictly worse off.

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1 Introduction

When the buyer's and seller's values are independent draws from uniform distributions, it is well known that the double auction of Chatterjee and Samuelson (1983) has a linear equilibrium that implements the socially optimal mechanism, giving equal weights to the buyer and seller and respecting incentive compatibility and individual rationality constraints while balancing the budget (Myerson and Satterthwaite, 1983). Assuming that the buyer and seller can only trade via a broker, this note first derives a transfer augmented double auction that maximizes

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the broker's expected profit, subject to incentive compatibility and individual rationality. Such a mechanism is called broker optimal.[1] We also derive the transfer augmented double auction that induces ex post efficient trade yet runs a deficit.

The note then shows that a bid and ask price setting market maker who trades with a continuum of buyers and sellers with values drawn from the uniform and who faces competition from a random matching market nets the same profit when the terms of trade in the random matching market are determined by (i) Nash bargaining, (ii) take-it-or-leave-it offers, (iii) a broker optimal double auction.[2] The note thus provides an analytically tractable modeling device that dispenses with the unsatisfactory assumptions that either buyers' and sellers' values are private information when dealing with the market maker but not in the random matching market (as under Nash bargaining/split-the-surplus) or that an optimal mechanism is employed by the market maker but not in the random matching market (as is the case e.g. with take-it-or-leave-it offers).

The remainder of this note is structured as follows. Section 2 derives the broker optimal double auction. Section 3 analyzes competition between a price posting market maker and a random matching market. Section 4 briefly discusses the results.

2 Transfer Augmented Double Auctions

Setup. There is one buyer whose value v for an indivisible good of known quality is drawn from the uniform on $[\underline{v}, \overline{v}]$ and one seller whose cost c of selling the good is independently drawn from the uniform on $[\underline{c}, \overline{c}]$, where $\underline{v} \leq \underline{c} < \overline{v} \leq \overline{c}$.[3] The buyer and seller can only trade via a broker who offers the following double auction. Letting b and s be the bids submitted by the buyer and seller, respectively, trade takes place if and only if $b \geq s$. Whenever this is the case, the buyer pays the transaction price $(b+s)/2$ to the seller. Moreover, both the buyer and the seller pay a fixed fee $\tau \geq 0$ to the broker if trade takes place. All agents are risk-neutral, and preferences are quasilinear, so that the buyer's payoff upon receiving the good and paying p is $v - p$ while the seller's payoff upon receiving the net payment p and selling the good is $p - c$.

Equilibrium. We now construct the (Bayes Nash) equilibrium where both the buyer and the seller employ linear bidding strategies. To that end, assume that the buyer with value v submits the bid $b(v) = \beta_0 + \beta_1 v$ and the seller with cost c submits the bid $s(c) = \sigma_0 + \sigma_1 c$. If the seller employs such a strategy, the buyer's expected payoff when submitting the bid b, given a value v, is $\int_{\underline{c}}^{(b-\sigma_0)/\sigma_1} [v - \tau - (b + \sigma_0 + \sigma_1 c)/2]\, dc/(\overline{c} - \underline{c})$. Similarly, the expected

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[1] For another practical mechanism, called fee setting mechanism, that is broker optimal for a large family of distributions, see Loertscher and Niedermayer (2010).

[2] Variants of this model have been analyzed by, amongst others, Gehrig (1993), Spulber (1999, 2002) and Loertscher (2007).

[3] These conditions ensure that the (ex ante) probability of trade is positive and the (interim) probability of trade for all realized types is less than one.

payoff of the seller with cost c when bidding s is $\int_{(s-\beta_0)/\beta_1}^{\overline{v}} [(\beta_0 + \beta_1 v + s)/2 - \tau - c]\, dv/(\overline{v}-\underline{v})$. The first-order condition for the buyer is $2v - 2\tau - 3b + \sigma_0 + \sigma_1 \underline{c} = 0$ and the seller's first-order condition is $\beta_1 \overline{v} + \beta_0 - 3s + 2\tau + 2c = 0$. Notice that the second-order conditions are satisfied strictly. Rearranging the first-order conditions yields $b = (\sigma_0 + \sigma_1 \underline{c} - 2\tau)/3 + 2v/3$ and $s = (\beta_0 + \beta_1 \overline{v} + 2\tau)/3 + 2c/3$. If these are to be of the form conjectured, then $\beta_1 = \sigma_1 = 2/3$, $\beta_0 = \frac{\sigma_0 + \sigma_1 \underline{c} - 2\tau}{3}$ and $\sigma_0 = \frac{\beta_0 + \beta_1 \overline{v} + 2\tau}{3}$ has to hold. Solving these equations yields $\beta_0 = -\tau/2 + \overline{v}/12 + \underline{c}/4$ and $\sigma_0 = \tau/2 + \underline{c}/12 + \overline{v}/4$. Thus, the bidding strategies

$$b(v) = -\frac{\tau}{2} + \frac{\overline{v}}{12} + \frac{\underline{c}}{4} + \frac{2}{3}v \tag{1}$$

$$s(c) = \frac{\tau}{2} + \frac{\underline{c}}{12} + \frac{\overline{v}}{4} + \frac{2}{3}c \tag{2}$$

constitute an equilibrium of the fee augmented double auction. Observe that a buyer of type $v < v_0$, where v_0 satisfies $b(v_0) = s(\underline{c}) \Leftrightarrow v_0 = 3\underline{c}/4 + \overline{v}/4 + 3\tau/2$, submits a bid that will never lead to trade and, consequently, will never induce any payments in equilibrium. For these types of the buyer, any bid $b < s(\underline{c})$ will be an equilibrium bid. For analogous reasons, a seller with cost $c > c_0$, where c_0 satisfies $b(\overline{v}) = s(c_0) \Leftrightarrow c_0 = -3\tau/2 + 3\overline{v}/4 + \underline{c}/4$, never trades in equilibrium. Therefore, any bid $s > b(\overline{v})$ will be optimal for these seller types.

Broker Optimal Double Auction. We first derive the transfer augmented double auction that is optimal for the broker.

Proposition 1 *The transfer augmented double auction with $\tau = (\overline{v} - \underline{c})/6$, where the buyer and seller play the strategies in (1) and (2), is a broker optimal mechanism if $\overline{v} > 2(\underline{v} - \overline{c}) + \underline{c}$.*

Proof: The broker optimal allocation is to have trade iff the buyer's virtual valuation, which in this application is $2v - \overline{v}$, exceeds the seller's virtual cost, which here is $2c - \underline{c}$ (see e.g. Myerson and Satterthwaite, 1983). Rearranging $2v - \overline{v} \geq 2c - \underline{c}$ yields $v \geq c + (\overline{v} - \underline{c})/2$. In the linear equilibrium of the fees augmented double auction, trade occurs iff

$$b(v) \geq s(c) \Leftrightarrow v \geq c + (\overline{v} - \underline{c})/4 + 3\tau/2. \tag{3}$$

Since $c + (\overline{v} - \underline{c})/4 + 3\tau/2 = c + (\overline{v} - \underline{c})/2$ for $\tau = (\overline{v} - \underline{c})/6$, it follows that the fee augmented double auction in Proposition 1 implements the broker optimal allocation rule. That there are individually rational equilibrium payments that implement this allocation rule follows from the fact that the strategies in (1) and (2) are equilibrium strategies. The allocation rule 'let buyer and seller trade iff $v \geq c + (\overline{v} - \underline{c})$' is broker optimal if and only if it is optimal for the broker that some types of the buyer and seller do not trade, which happens if $2\underline{v} - \overline{v} < 2\overline{c} - \underline{c} \Leftrightarrow \overline{v} > 2(\underline{v} - \overline{c}) + \underline{c}$ and that some types do trade, which happens if and only if $\overline{v} > \underline{c}$ (see, again, Myerson and Satterthwaite, 1983). ■

Notice that under the broker optimal double auction the intermediary nets 2τ iff there is trade. For v and c uniform on $[0, 1]$, $\tau = 1/6$ and trade takes place iff $v \geq c + 1/2$.

So the intermediary's expected profit then is $2\tau\int_{1/2}^{1}\int_{0}^{v-1/2} dcdv = 1/24$, which, of course, is the same as the broker's profit under the dominant strategy implementation of Myerson and Satterthwaite (1983).

The intuition why appropriately chosen fixed fees τ that are charged to the buyer and seller in case of trade induce a double auction that is broker optimal is fairly simple. The double auction with uniformly distributed values and zero fees is well known to have a linear equilibrium. In this equilibrium, trade occurs iff $v \geq c + (\overline{v} - \underline{c})/4$. The broker optimal mechanism is such that trade occurs iff $v \geq c + (\overline{v} - \underline{c})/2$. By choosing $\tau > 0$, the buyer's net value decreases to $v - \tau$ and the seller's net cost increases to $c + \tau$. Since there is a linear equilibrium when fees are zero, there will be a linear equilibrium when fees are positive, where trade occurs iff $v \geq c$ plus a constant that is larger than $(\overline{v} - \underline{c})/4$. By choosing τ appropriately, this constant can be made to equal $(\overline{v} - \underline{c})/2$.

Notice also that at $\tau = (\overline{v} - \underline{c})/6$, $v_0 = c_0 = (\overline{v} + \underline{c})/2$. Since $b(v) + \tau < v$ for all $v > v_0$ and $s(c) - \tau > c$ for all $c < c_0$, the fee augmented double auction not only respects individual rationality constraints ad interim, but also ex post.

Ex Post Efficient Double Auction. Let us also derive the transfer augmented double auction that generates ex post efficient trade. This double auction respects ex post (and consequently ad interim) individual rationality constraints, yet runs a deficit. Ex post efficiency demands that trade takes place iff $v \geq c$, which in the linear equilibrium of the transfer augmented double auction is equivalent to requiring $(\overline{v} - \underline{c})/4 + 3\tau/2 = 0$ (see (3)). Thus, the transfer augmented double auction that induces ex post efficient trade is as follows:

Proposition 2 *The transfer augmented double auction with $\tau = -(\overline{v} - \underline{c})/6$, where the buyer and seller play the strategies in (1) and (2), induces ex post efficient trade if $\overline{v} > 2(\underline{v} - \overline{c}) + \underline{c}$.*

The proof mimics the one of Proposition 1 and is therefore omitted. Notice that for v and c uniform on $[0, 1]$, $\tau = -1/6$ and trade takes place iff $v \geq c$. So the expected deficit of the ex post efficient double auction is $2\tau\int_{0}^{1}\int_{0}^{v} dcdv = -1/6$. This is, of course, the same as the subsidy necessary for ex post efficient trade derived by Myerson and Satterthwaite (1983) under the same distributional assumptions. Notice that the funds to cover the deficit may come from the buyer and the seller if they can contract ex ante.[4]

3 Competing Exchanges

Let us now turn to a simple model of a market making intermediary who competes with a simultaneously open random matching market. Models of this kind have been studied by,

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[4] There are applications where such ex ante payments are not implausible. Suppose e.g. that long before their actual valuations and costs are known the buyer and seller register on a trading platform on which they will interact repeatedly. The registration fees may then serve as such ex ante payments.

amongst others, Gehrig (1993), Spulber (1999, 2002), Rust and Hall (2003) and Loertscher (2007).

3.1 Setup

There is a continuum of buyers of mass one whose valuations v for a unit of a homogeneous good are distributed uniformly on [0,1], and there is a continuum of sellers with mass one whose (opportunity) costs c of selling a unit are distributed uniformly on [0,1]. If the buyer with valuation v buys the good at price p with $p \leq v$ his net utility is $v - p$. Analogously, a seller with cost c derives utility $p - c$ if he sells at price p.

Buyers and sellers can either participate in a random matching market, trade with a market making intermediary at ask and bid prices p^a and p^b or remain inactive. These choices are mutually exclusive. Agents whose expected utility from participating in the random matching market is not positive remain inactive. This assumption prevents the matching market from being overcrowded.[5] In the random matching market there is one round of uniform random matching with probability $\lambda \in (0,1)$.[6] We will study four versions of the model that differ in the way the terms of trade in the random matching are determined, which are spelled out below.

The market maker maximizes his profit $\pi(p^a, p^b) = (p^a - p^b)q(p^a, p^b)$ by choosing (p^a, p^b), where $q(p^a, p^b) \equiv \min\{q^B, q^S\}$ is the equilibrium quantity traded and q^B and q^S are the mass of buyers and sellers who want to trade with him.

The timing is as follows. The intermediary first chooses (p^a, p^b). Observing these prices, all buyers and sellers decide simultaneously whether to join the intermediary, to participate in the search market or to remain inactive. We also assume that the intermediary has enough money and is committed to pay p^b to all sellers who want to sell to him. Disregarding the non-linear equilibria no trade equilibria in double auctions and unstable equilibria, this assumption guarantees a unique equilibrium. Buyers, sellers, and the market making intermediary, and if present, brokers, are risk-neutral.

3.2 Equilibrium

The equilibrium in all four versions of the model is such that buyers with $v \in [\overline{v}, 1]$ and sellers with $c \in [0, \underline{c}]$ trade with the market maker, buyers with $v \in (\underline{v}, \overline{v})$ and sellers with $c \in (\underline{c}, \overline{c})$ participate in the random matching market and all other agents remain inactive, where $0 < \underline{v} < \overline{v} < 1$ and $0 < \underline{c} < \overline{c} < 1$.[7] Let $V_B(v)$ and $V_S(c)$ be the expected utility

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[5] It can be justified as the limit case when random matching market participation involves a small but positive fixed cost when this fixed cost goes to zero.

[6] This is literally true only if the mass of buyers equals the mass of sellers, which is true in equilibrium and will not be changed by unilateral deviation since agents have measure zero. If there are, say, twice as many buyers as sellers, each seller would be matched with probability λ while each buyer would be matched with probability $\lambda/2$.

[7] Two qualifications are in order. First, there is always an equilibrium where no one joins the random matching market. But this equilibrium is not stable and hence we dismiss it. Second, in the variants where the random

from participating in the random matching market for a buyer of type v and a seller of type c, respectively. Two pairs of indifference conditions are key for the equilibrium.[8] Buyer $\overline{v}$ and seller $\underline{c}$ must be indifferent between trading with the market maker and joining the random matching market. Thus, $\overline{v}$ and $\underline{c}$ satisfy

$$\overline{v} - p^a = V_B(\overline{v}) \quad \text{and} \quad p^b - \underline{c} = V_S(\underline{c}). \tag{4}$$

Equation (4) is critical for the equilibrium profit of the market maker because it determines the spread the market maker faces. To see this, rearrange the terms in (4) and then subtract to get the spread

$$p^a - p^b = \overline{v} - \underline{c} - [V_B(\overline{v}) + V_S(\underline{c})]. \tag{5}$$

Second, $\underline{v}$ and $\overline{c}$ are such that $V_B(\underline{v}) = 0$ and $V_S(\overline{c}) = 0$.

Nash Bargaining Nash bargaining amounts to splitting the surplus in the present setup, the buyer getting fraction α and the seller $1-\alpha$ with $\alpha \in (0,1)$. Therefore, a buyer of type v derives s surplus of $\alpha(v-c)$ if matched to a seller of type c with $c \le v$ and a surplus of 0 otherwise. Because even very inefficient traders can derive some surplus from joining the random matching market, $\overline{v} = \overline{c}$ and $\underline{v} = \underline{c}$ will hold under Nash bargaining. The expected utility of buyer v from joining the random matching market is $V_B(v) = \lambda\alpha \int_{\underline{c}}^{v} [v-c] \frac{dc}{\overline{c}-\underline{c}} = \frac{\lambda\alpha(v-\underline{c})^2}{2(\overline{c}-\underline{c})}$. For the indifferent buyer, one gets $V_B(\overline{v}) = \lambda\alpha(\overline{v}-\underline{c})/2$. Analogous reasoning leads to the conclusion $V_S(\underline{c}) = \lambda(1-\alpha)(\overline{v}-\underline{c})/2$.

Take-it-or-leave-it Offers Assume now that upon being matched in the random matching market the buyer is allowed to make a take-it-or-leave-it offer with probability α. With probability $1-\alpha$ the seller makes a take-it-or-leave-it offer with $\alpha \in (0,1)$. A buyer with valuation $v \in [\underline{v}, \overline{v}]$ who is given the opportunity of making an offer sets the price p to maximize $\int_{\underline{c}}^{p} (v-p)dc/(\overline{c}-\underline{c})$, yielding $p_B(v) := (v+\underline{c})/2$ as solution. Observe that as under Nash bargaining, take-it-or-leave-it offers will attract very inefficient traders into the random matching market, so that $\overline{v} = \overline{c}$ and $\underline{v} = \underline{c}$ will hold. Similarly, a seller with cost $c \in [\underline{c}, \overline{c}]$ who is given the option of making the price offer chooses p to maximize $\int_{p}^{\overline{v}} (p-c)dv/(\overline{v}-\underline{v})$, which yields $p_S(c) := (\overline{v}+c)/2$ as solution. Observe that $p_S(c) \le v \Leftrightarrow c \le 2v - \overline{v}$. The buyer's expected utility from search is therefore $V_B(v) = \lambda \left[\alpha \int_{\underline{c}}^{p_B(v)} (v - p_B(v))dc + (1-\alpha) \int_{\underline{c}}^{\max\{2v-\overline{v},\underline{c}\}} (v - p_S(c))dc\right] / (\overline{c}-\underline{c})$. For $v = \overline{v}$, this simplifies to $V_B(\overline{v}) = \lambda(\overline{v}-\underline{c})/4$. Analogously, the seller with cost $\underline{c}$ has an expected utility from search market participation of $V_S(\underline{c}) = \lambda(\overline{v}-\underline{c})/4$.

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matching market is characterized by double auctions, we exclusively focus on the linear equilibrium of the double auction.

[8] On top of these indifference conditions, the out-of-equilibrium conditions must be satisfied that buyers with $v > \overline{v}$ and sellers with $c < \underline{c}$ are better off joining the intermediary than deviating to the random matching market. These can be shown to be satisfied strictly for all four bargaining procedures considered.

Broker Optimal Double Auction Suppose that in addition to sellers and buyers the random matching market is also host to a continuum of brokers and that the frictions are such that buyers and sellers can only trade via a broker. Accordingly, a match now consists of a triple buyer, seller and broker.[9] Matching is still uniform random, and the probability that a buyer and a seller are matched is λ. Observing the market maker's prices (p^a, p^b) brokers offer transfer augmented double auctions with $\tau = (\overline{v} - \underline{c})/6$. The probability of being matched is independent of the fee chosen by the broker.

Notice that a seller with c greater than $\overline{v} - (\overline{v} - \underline{c})/2$ would never trade in the random matching market and will therefore not join it. Thus, $\overline{c} = (\overline{v} + \underline{c})/2$ holds. Similarly, $\underline{v} = (\overline{v} + \underline{c})/2$ can be established. A buyer's expected utility from joining the random matching market is $V_B(v) = \lambda \int_{\underline{c}}^{v-(\overline{v}-\underline{c})/2} [v - \tau - (b(v) + s(c))/2] \frac{dc}{\overline{c}-\underline{c}}$. Making use of the expression for $\overline{c}$ and integrating out yields $V_B(\overline{v}) = \lambda(\overline{v} - \underline{c})/4$. Analogously, one can establish $V_S(\underline{c}) = \lambda(\overline{v} - \underline{c})/4$.

Socially Optimal Double Auction Suppose now the matching market is characterized again by direct matchings of buyer and seller pairs, but that the buyer and seller in a match play the linear equilibrium of a standard double auction (i.e. $\tau = 0$). Notice that this equilibrium induces trade iff $v \geq c + (\overline{v} - \underline{c})/4$ and that the equilibrium is socially efficient in the sense of maximizing ex ante expected gains from trade subject to individual rationality, incentive compatibility and balanced budget constraints. Therefore, sellers with $c \geq \overline{c} = \overline{v} - (\overline{v} - \underline{c})/4$ and buyers with $v \leq \underline{v} = \underline{c} + (\overline{v} - \underline{c})/4$ will remain inactive. One can then show that $V_B(\overline{v}) = \frac{3\lambda}{8}(\overline{v} - \underline{c}) = V_S(\underline{c})$.

The optimal (p^a, p^b) will be such that $1 - \overline{v} = \underline{c}$ for otherwise the market maker would attract either more buyers or more sellers. Since he can only trade the minimum of the two numbers he could change his prices in a way that preserves the spread $(p^a - p^b)$ and strictly increases the quantity he trades. Thus, the market maker's quantity traded will be $q = \underline{c} = 1 - \overline{v}$. Substituting these terms in the expressions for $V_B(\overline{v})$ and $V_S(\underline{c})$ just obtained, the spread $p^a - p^b$ in (5) becomes a function of the quantity q only. For Nash bargaining, take-it-or-leave-it offers and broker optimal double auctions, the spread is:

$$p^a - p^b = \left(1 - \frac{1}{2}\lambda\right)(1 - 2q) \tag{6}$$

For the socially optimal mechanism, $p^a - p^b = \left(1 - \frac{3}{4}\lambda\right)(1 - 2q)$. Thus, the market maker will be indifferent between the former three arrangements for the random matching market and will prefer any of these to the socially optimal mechanism.

The equilibrium quantity traded by the market maker will be $1/4$, which implies an equilibrium spread of $(1 - \frac{1}{2}\lambda)/2$ for Nash bargaining, take-it-or-leave-it offers, and broker optimal

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[9] Rust and Hall (2003) analyze a similar market structure except that every broker (middleman in their jargon) is matched to a continuum of buyers and sellers in their model, so that price posting is optimal for the broker (middleman).

double auctions and a spread of $(1-\frac{3}{4}\lambda)/2$ for the socially optimal mechanism.

Note that while the first three mechanisms in the search market lead to different utilities for inframarginal traders, they lead to the same bid-ask spread since the sum of the utilities of the marginal traders $V_B(\overline{v}) + V_B(\underline{c})$ is the same. For take-it-or-leave-it offers and broker optimal double auctions the ask price is $p^a = \frac{3}{4} - \frac{1}{8}\lambda$ and the bid price is $p^b = \frac{1}{4} + \frac{1}{8}\lambda$. For Nash bargaining $p^a = \frac{3}{4} - \frac{1}{4}\alpha\lambda$ and $p^b = \frac{1}{4} + \frac{1}{4}(1-\alpha)\lambda$. It is worth noting that for Nash bargaining, a mechanism is at work that is akin to one described in the two-sided markets literature (see e.g. Rochet and Tirole, 2006): if the buyer has a strong bargaining position in the search market (α large), the market maker will subsidize him (reduce p^a) and tax the seller (reduce p^b) in order to attract traders on both sides of the market, while keeping the bid-ask spread constant.

4 Discussion

The present note provides a way of modeling random matching markets and market making in a consistent way in that it permits optimal mechanisms to be used in both exchanges and does away with the assumption that values and costs are private information when dealing with the market maker but not when trading in the random matching market. Though this note has focused on double auctions, the revenue equivalence theorem implies that any other optimal mechanism in the search market, like e.g. the dominant strategy mechanism of Myerson and Satterthwaite (1983) or the fee setting mechanism of Loertscher and Niedermayer (2010), would lead to the same results. The market maker is worse off when a socially efficient mechanism is employed in the random matching market that respects incentive compatibility, individual rationality and budget balance constraints, yet is ex post less efficient than (ex post efficient) Nash bargaining. This may come as a surprise at first. It is due to the fact that Nash bargaining attracts many inefficient traders whose presence decreases the expected utility from joining the random matching market for the critical buyer and seller by more than does private information and the associated impossibility of ex post efficient trade.

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