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ABSTRACT

Many markets have organizations that influence or try to establish norms concerning when offers can be made, accepted and rejected. Examining a dozen previously studied markets suggests that markets in which transactions are made far in advance are markets in which it is acceptable for firms to make exploding offers, and unacceptable for workers to renege on commitments they make, however early. But this evidence is only suggestive, because the markets differ in many ways other than norms concerning offers. Laboratory experiments allow us to isolate the effects of exploding offers and binding acceptances. In a simple environment, in which uncertainty about applicants' quality is resolved over time, we find inefficient early contracting when firms can make exploding offers and applicants' acceptances are binding. Relaxing either of these two conditions causes matching to take place later, when more information about applicants' qualities is available, and consequently results in higher efficiency and fewer blocking pairs. This suggests that elements of market culture may play an important role in influencing market performance.

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I. Introduction

Different markets have different rules, norms, and expectations about how and when offers will be made, accepted, and rejected. For example, in some labor markets, it is conventional for employers to make exploding offers, to which candidates must reply before receiving other offers, while in other markets it is customary for all offers to remain open long enough to allow candidates to compare multiple offers. Similarly, norms differ concerning the circumstances under which a candidate may honorably change her mind about an offer she has accepted. These differences--whether they are enshrined in legally enforceable rules, or simply in expected behavior, and whether they are dictated by the larger market environment, or constitute different equilibria within a given market—can influence who makes offers to whom, at what time, and what outcome is produced.

Many markets have sought to change their market cultures in these respects, to promote more orderly markets, to control the timing of the market until information is available, and to produce more efficient matches between firms and applicants. In over a dozen of these markets that we know of, there are organizations of market participants that spend a good deal of effort addressing how and when offers are made, accepted, and rejected (see Table 1).

Because these markets are all different, it is difficult to make simple comparisons of the various institutions they have created to shape offers and acceptances. But examining these markets together suggests a pattern: markets in which transactions are made at early, uncoordinated times are those in which there are both exploding offers (i.e. offers which must be accepted or rejected before other offers can be considered), and binding commitments.

In the next section we look in some detail at two of these markets that will be familiar to most of our readers, the markets for undergraduate and graduate admissions to American colleges and universities. In Section III we develop some theory, for a simple environment which we then use to test our hypothesis in a laboratory experiment, reported and analysed in Sections IV-VI.

Table 1: Some Institutions related to market culture[1]:

Market	Institution that tries to regulate timing of offers	Description
Graduate School Admissions	Council of Graduate Schools (CGS)	Exploding offers discouraged, and acceptances before April 15 non-binding (see text)
Undergraduate College Admissions	National Association for College Admission Counseling (NACAC)	Binding early decision, non-binding early action
U.S. , Canadian, and British Medical Residencies	National Resident Matching Program (NRMP), Canadian Resident Matching Service (CaRMS), various regional matches in Britain.	Centralized clearinghouse
Medical Fellowships	Specialty Matching Services (SMS)	Centralized clearinghouse
Clinical Psychology	Association of Psychology Postdoctoral and Internship Centers (APPIC)	Centralized clearinghouse
Lawyers (particularly in large law firms)	National Association for Law Placement (NALP)	Principles and Standards for Law Placement and Recruitment Activities
Federal Judicial Clerkships	Judicial Conference of the United States (and various ad hoc committees of judges)	Law Clerk Hiring Plan (http://www.cadc.uscourts.gov /lawclerk/)
Canadian Lawyers (articling positions)	Regional Law Societies (e.g. Law Society of Upper Canada)	Articling Recruitment Procedures (centralized match abandoned for 2004-5 articling term)
Japanese University Graduates	The Japan Federation of Employers' Associations (Nikkeiren), Labor Ministry	Establishes guideline dates before which contracts should not be signed, and rules about interviewing.
Recruitment of MBA graduates	Individual business school recruiting offices	Regulations of on campus interviews, dates and duration of offers, etc.
US College Graduates—on campus recruiting	National Association of Colleges and Employers (NACE) www.naceweb.org/about/principl.html	Guidelines for good conduct that discourage reneging of acceptances by students and undue time pressure of acceptance and encouragement to renege on another offer.
Postseason college football bowls	Bowl Championship Series (BCS)	Confederation of bowls and conferences
Sororities	National Panhellenic Conference	Regulates bidding procedure

[1] For discussions of those markets not described in the present paper, see e.g. Roth and Xing 1994, 1997, Roth 1991, Mongell and Roth 1991, Avery et al. 2001. In addition to these markets, there are many more in which institutions exist to regulate the details of how and when offers are made. For example, many American professional sports (e.g. basketball, football, baseball, hockey) have formal drafts, and the recruitment of college athletes is heavily regulated by the NCAA. In addition to markets that seek to regulate the timing of interviews and offers, others seek to influence timing by establishing facilitating institutions. For example, in a variety of academic disciplines, the new assistant professor market is facilitated by the annual meetings of the relevant professional societies. For a discussion of matching students to public schools, see Abdulkadiroglu and Sonmez (2003) and Chen and Sonmez (2003).

II. Graduate and undergraduate admissions

One market in which a good deal of effort has been spent shaping and discussing these aspects of culture is the market for graduate students. The Council of Graduate Schools has, since the mid 1960's, attempted to establish norms concerning how graduate students are recruited. Over 350 American universities subscribe to its resolution, which is distributed to applicants by graduate programs, and states in part:

> "Students are under no obligation to respond to offers of financial support prior to April 15; earlier deadlines for acceptance of such offers violate the intent of this Resolution. In those instances in which a student accepts an offer before April 15, and subsequently desires to withdraw that acceptance, the student may submit in writing a resignation of the appointment at any time through April 15. However, an acceptance given or left in force after April 15 commits the student not to accept another offer without first obtaining a written release from the institution to which a commitment has been made."
> (http://www.cgsnet.org/pdf/resolution.pdf)

The resolution is accompanied by some explanatory discussion of how the resolution should be honored in the breach, which reads in part as follows (www.cgsnet.org/PublicationsPolicyRes/resolutions.htm#resolution1):

> "Students may be waiting for offers from several institutions so that they can compare and make a decision. One of the complaints we hear is that some departments make offers quite early and insist that students respond quickly or lose the offer. According to the Resolution, the option available to the student in this situation who wishes to review several offers is to accept each one and then, by April 15, resign from all but one. But this places the student in an awkward position and really violates the spirit of the Resolution, that is, that acceptances should not be made casually.
>
> "A better approach is for institutions to give students until April 15 to make decisions regarding appointments. Students often consider multiple offers, and this option provides a reasonable opportunity for them to do so. This would not preclude institutions asking students to accept or reject offers in a timely manner."

Note that the resolution attempts to foster a market culture under which exploding offers are discouraged directly, and also indirectly by being made less enforceable. That is, the resolution suggests that a student who accepts an exploding offer with a deadline before April 15, but subsequently declines it before April 15, should not be thought of as behaving badly. This reduces the cost of reneging on (and hence also of accepting) an

exploding offer, in a world with opportunities for repeated interactions, in which social norms may have some force.[2]

Similar concerns, and attempts to alter market culture, have played large roles in attempts to organize entry level labor markets for doctors, for lawyers, and college admissions at the undergraduate level. For example, doctors engage in a centralized labor clearinghouse, the medical "match," that attempts to inculcate certain norms of participation (Roth, 1984, 1991, Roth and Peranson 1999). One of these is that employers are not supposed to ask applicants to make commitments prior to the match, or to indicate how they will record their preferences in the match. Surveys of medical students reveal that when they are nevertheless asked for such indications and commitments, they feel free to answer encouragingly, without constraining their subsequent behavior in the match (see e.g. Anderson et al., 1999; Carek et al., 2000; Pearson and Innes, 1999; Teichman et al., 2000). In the medical resident market, like the graduate admissions market, the rules of the market and the corresponding market culture result in current operations of those markets in which early matches seem not to be very common.

In contrast, law students who apply for appellate court clerkships are frequently given exploding offers, and are almost never reported to renege on them. And indeed in contrast to the graduate student and medical resident market, the market for law clerk positions has in recent years cleared very early, despite numerous attempts to control and push back the timing of the market (Roth and Xing 1994; Avery, Jolls, Posner, and Roth, 2001).[3]

[2] And by marking acceptances on April 15 as more binding than those made before, it also makes it less attractive for departments to make new offers after the 15th. So, for example, the chair of the graduate student recruiting committee in the Economics department of a competitive New England university wrote of a recent recruiting year that "we do not make any offers after April 15, 5 pm. This year lots happened between 2 and 5 pm of April 15. Nobody on our waiting list had accepted other offers; they were told to wait until the last minute." Needless to say, in a market with a lot of action near a deadline there may be congestion, with some offers being rejected when there is insufficient time to make new offers, a topic to which we will return later (and see Roth and Xing 1997 for a discussion of congestion in a labor market).

[3] The latest attempt to control dates of clerkship appointments has been made in 2003. Of course, some elements of a market's culture regarding whether certain commitments are binding can be explained at least in part in terms of the amount of repeated interaction in these markets. Hospitals and new doctors are part of a large national market, and a doctor who goes to the West coast is unlikely to interact closely with a hospital on the East coast (whose offer he might have reneged on). Appellate judges are harder for lawyers to avoid. But repetition, or the lack of it, isn't destiny. Market failures are sometimes fixed or avoided by changes in the culture. In the markets mentioned in Table 1, for example, a good deal of effort has been

Even in a given market, commitments made at different times may have different force. In the undergraduate college admissions process, students' acceptance of an early offer of admission from an "early decision" college, made in the Fall of a student's senior year in high school, is considered binding (Avery, Fairbanks, and Zeckhauser, 2003), while acceptance of offers later in the year are much less binding. [4]

The rules and customs surrounding early offers have been in flux, following a September, 2001 meeting of the National Association for College Admission Counseling (NACAC), at which it was resolved that students applying to a binding Early Decision program should still be allowed to apply to as many nonbinding Early Action programs as they wish (http://www.nacac.com/policies.html). In response, Harvard changed its early action requirements to indicate that students could apply early action to Harvard even if they were applying early elsewhere. It was initially unclear whether Harvard would allow people who were accepted to Harvard under its nonbinding early action program to attend if they were simultaneously accepted in a binding early decision program by another college. While Harvard subsequently indicated that it would expect students to honor commitments made to other schools, it appears likely that some students in this situation might question whether their commitment to attend the other school is legally binding, and this might eventually make binding early decision programs less attractive to college admissions officers. In this connection, Princeton and Brown have indicated that they will not comply with the NACAC decision, and will continue to require students who apply to their early decision programs to indicate in the contract they sign, not only that they will attend if admitted, but also that they are not

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spent trying to alter the market culture. The market for undergraduate admissions, discussed next, will make clear why we think that market culture can't be deduced from market structure, since at different times in a given season, that market exhibits different market cultures.

[4] Avery et al. (2003) describing the situation before 2002, note that most selective colleges set a regular application deadline on or about January 1, and an early application deadline on or about November 1. Colleges typically choose one kind of early application program, called either "Early Decision," or "Early Action." Students who apply early to an Early Decision program can only submit one early application, and sign a contract that they will attend if accepted. In most cases, students who apply Early Action can apply early to more than one Early Action college. These colleges then notify early applicants of a decision, "Admit," "Reject," or "Defer", by early-to-mid December. Early Decision colleges submit lists of their early admits to rival colleges with a note that those ED admits are expected to withdraw all other applications. The rule that students could submit only one early decision application was enforced in part through actions of the high school guidance counselors, while the binding nature of early acceptances was enhanced by the practice of other colleges not to consider applications from other colleges' early admits.

applying early elsewhere (see e.g. Hoover, 2002, Rosenheck, 2002).[5] These developments indicate that colleges are sensitive to the delicacy of the arrangements that make binding early admissions a reliable commitment, and that they expect students to respond to the resulting strategic incentives.[6]

In contrast, later on in the same market, regular admits are required to reply to offers of admission by May 1, but many students are left on "waiting lists" beyond that date, and are relatively free to cancel their acceptance when they are given an offer from a waiting list.[7] For example, Harvard's letter to students who have been placed on the waiting list states:

> "We recognize that you must make plans at another college while you await our final decision. Please be assured that all colleges will understand your situation…"

These examples, along with those mentioned in table 1, suggest some support for the hypothesis that markets in which transactions are made early are those in which there are both exploding offers (i.e. offers which must be accepted or rejected before other offers can be considered), and binding commitments.

However, these markets differ in many ways, not only their culture regarding exploding offers and the degree to which a commitment is binding. Some markets are

[5] The situation is still fluid: On November 6, 2002, Yale and Stanford announced that they would replace their binding early decision program with a (non-binding) early action program, but not allow students to also apply early action anywhere else. On April 10, Harvard announced that it will no longer allow its early action applicants to apply early elsewhere starting in the Fall of 2003. In August, the NACAC announced a "moratorium on Enforcement" on the "early action 'without restriction'" policy because of changes in admissions trends, such as the growing popularity of early applications (Young, 2003).

[6] Karen Arenson (2003) reports the number of applications Harvard, Stanford and Yale received to their new "single early admissions" program in the Fall of 2003. Harvard, which had made its early action program more restrictive through the "single-choice" clause saw early applications fall by 47%. Stanford and Yale, which had relaxed their binding early decision programs to a nonbinding, but "single-choice" early action program saw big increases in early applications (62% for Stanford and 42% for Yale). Princeton and MIT, which did not change their policies, saw their applications fall by 23 and 22 percent respectively, presumably being affected by the changes of other programs' admission plans. Arenson quotes Richard Zeckhauser as follows: "Very little has happened in the last year at Harvard, Princeton, Yale, or Stanford to shift students preferences for those colleges so dramatically. What students are doing is trying to maximize their chances of getting in; they are behaving strategically."

[7] Colleges often require deposits at the time of acceptance in May of no more than a few hundred dollars (despite yearly tuitions in the five figures), and waiting lists cause admitted freshpersons to reconsider well into the summer. The resulting reduction in the number of students who will attend a given college out of those who initially accepted the offer of admission, and placed a deposit, is known as the "summer melt" (Bombardieri, 2003).

very large (college admission), some are much smaller (law clerks or college football bowls), in some markets monetary compensation plays a big role in clearing the market (new associates of large law firms and college football bowls) in others, wages are set exogenously (law clerkships).

An ideal test for the effects of market culture on the timing of the market would be a set of markets that differ only in how offers are made and responded to, but not in any other way. Markets created in the laboratory offer us the possibility of making just such comparisons.

In what follows, we consider a simple environment, in which early matches are unambiguously inefficient, because information about the applicants' quality, which determines the efficient matching, is only known in later periods. The efficiency of an outcome in our environments will be measured as the total welfare of market participants.[8] We consider three kinds of markets. In the first, firms can make exploding offers, and acceptances are binding. We compare this with two alternative environments. In one of these, applicants may renege on their acceptance of an exploding offer at a small cost, and in the other, only open offers may be made, that is, offers without a constraining deadline.

These environments allow for many equilibria, including some in which all matches are agreed upon inefficiently early. However, all environments have a perfect equilibrium that induces efficiently late matches. Nevertheless, the late matching equilibrium is less robust, more fragile to the presence of applicants who deviate from equilibrium behavior when offers are exploding and acceptances are binding.

Experiments will allow us to make controlled comparisons between these different regimes, and also to investigate issues about which theory is relatively silent, namely the multiplicity of equilibria, and the hypothesis that the fragility of the late matching equilibrium when firms can make exploding offers and acceptances are binding will make late matching less likely in those markets.

[8] While early matches may benefit some participants (such as lower quality firms that manage to hire higher quality applicants) total overall welfare will be reduced by early matchings in our experimental environment. For a discussion of the problems of measuring efficiency in naturally occurring markets, see Niederle and Roth (2003a), which shows that early transactions in the market for gastroenterologists decreased mobility in the market. (See also Niederle and Roth 2003b).

We will see that, in the environments we explore, the market unravels to inefficiently early contracts when firms are free to make exploding offers and acceptances are binding. But both the prevention of exploding offers, and the facilitation of reneges, change the market dynamics in a way that promotes later offers, greater efficiency, and the resulting matchings have fewer blocking pairs of firms and applicants.

III. Some theory of a simple environment

The behavior of participants in the markets discussed in Table 1 are often guided not only by fixed rules, but also norms and expected behavior, the whole culture of the market. Formal rules and informal rules often impose equally strong restrictions on possible and acceptable behavior of market participants. We will model these formal and informal rules about offers and responses as strict rules both in our theoretical discussion and when we implement markets experimentally. We can then evaluate the effect of different rules for making and rejecting offers, both theoretically and experimentally.

Our strategy for presenting some theory will be to use the simple environment which we will later implement in the experiments.

Consider a market with 5 firms and 6 applicants. Firms have a fixed quality, from 1 to 5, and applicants will eventually have a quality from 1 to 6. In each market a firm can hire one applicant and an applicant can work for one firm. A matched firm and applicant each earn the product of their qualities, unmatched market participants earn zero.

Each market lasts 9 periods. In periods 1, 4 and 7 each applicant receives an integer signal from 1 to 10 (uniform iid). The quality of each applicant is determined in period 7 through the relative ranking of the sum of their three signals. The applicant with the highest sum receives a quality of 6, the second highest a quality of 5, the lowest a quality of 1 (ties are broken randomly). Firms see all the applicants' signals as they become available over time, but applicants only receive information about their own signals.[9]

[9] This feature of the experimental environment is motivated by the situation in many markets, in which firms see a whole pool of applicants, but applicants may have difficulty knowing how they compare with other applicants.

Having three periods in which new information is revealed allows us to observe several "degrees" of inefficiency of early matching.[10]

Each information state lasts for 3 periods in which firms can make offers, and applicants decide whether to accept or reject them. This will help us to avoid exogenously imposed congestion, which occurs when firms may run out of time to make offers they would have liked to be able to make. In pure strategy equilibria, congestion does not occur, by assumption. However, in laboratory markets, even a small amount of coordination failure would lead to congestion, and potential congestion in late periods would provide an additional reason for firms to make early offers, and an additional source of inefficiency. (In naturally occurring markets, congestion is common; see the discussion in Roth and Xing 1997. Kagel and Roth (2000) report an experiment in which early matching arises in response to congestion.) Since we are interested here in early matching for reasons other than congestion, the experimental markets will allow 3 periods in which offers can be made and accepted, whenever new information is revealed. [11]

We consider two types of offers that can be made by firms:

An *exploding* offer is an offer that the applicant can only accept right away, i.e. in the same period in which it was made; if it is not accepted immediately, it is rejected.

An *open* offer is an offer the applicant can also hold (until period 9). That is, an applicant who receives an open offer may accept or reject it immediately, or may hold it, to accept or reject at a later period. An applicant must reject a held offer if he wishes to hold or accept another offer.[12]

In a given period, first all the firms decide what offers they will make. Each firm that is unmatched, and has no open offer being held by an applicant, may decide to make at

[10] It is possible that, after two signals, the applicant of the highest quality, or the applicant of the lowest quality, though not both, can be deduced by the firms, but not by the applicants (who do not see others' signals).

[11] While this avoids exogenously imposed congestion, congestion may develop endogenously, if applicants hold offers until late, or firms delay making offers. Roth and Ockenfels 2002 discuss congestion arising endogenously in an auction market, in which bidders delay making bids until near the close of the auction.

most one offer. Then each applicant learns of all offers he receives in that period before having to decide how to respond to each of them. If an applicant accepts the offer of a firm, the applicant and the firm are matched, and all market participants are informed about this. Offers are made in private; i.e. until they have been accepted they are not announced to the other firms and workers.

We consider three environments, characterized by different rules governing offers and responses. To keep the environments (and also the experimental instructions) as closely comparable as possible, firms in the experiment are allowed to issue open offers in all three conditions, what differs is only whether exploding offers are allowed and whether acceptances are binding.

Exploding offers: Firms can make exploding and open offers, and any acceptance is binding.[13]

Open offers: Firms can only make open offers. Once an applicant accepts an offer, the acceptance is binding.

Renege: Firms can make exploding and open offers. However an applicant who accepted an offer, and subsequently receives another offer, may renege on the former acceptance for a small fee, and accept the new offer. (We set the fee to be 1, which is smaller than the minimum improvement from accepting a match with a higher quality firm, since matches pay each applicant the product of his quality and the quality of the firm to which he is matched.)

All three treatments allow for a whole array of Bayesian Nash equilibria. For example, in each treatment, there is an equilibrium in which, after the first period, all the firms are matched. For example, the following strategies constitute an equilibrium in which all firms are matched in Period 1.

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[12] This is not an onerous constraint for the applicants, since they have strict, unchanging preferences over the firms. In our experimental environment, it reduces the cost to a firm of making an open offer, since it reduces the likelihood that an open offer will be held by an applicant who has no intention of taking it.

[13] One can think of the applicants' ability to make binding agreements as an agreement among firms to not make offers to applicants who accepted another firm's offer. Recall for example Harvard's decision to honor other universities' early decision acceptances.

Strategies of firms: Each firm i makes an open offer in period 1 to applicant i. A firm whose offer is rejected never makes another offer.

Strategies of applicants: Each applicant i in period 1 accepts an open offer from firm i and rejects any other offers (i.e. exploding offers, offers from other firms, and offers received in other periods).

These strategies constitute an equilibrium, as no firm has an incentive to deviate, given the strategies of applicants and vice versa. However, this equilibrium has the unattractive property of using weakly dominated strategies.

However, in each of the different conditions, there is a perfect Bayesian equilibrium that yields late matching and the efficient outcome. But we will see that there is reason to think that this result is less robust in the case of exploding offers and binding agreements than in the other two conditions. Proofs (and the statements of equilibrium strategies and beliefs) are contained in the Appendix.

Proposition 1: In the exploding offer treatment, when firms and applicants are all risk neutral, there is a perfect Bayesian equilibrium with efficient late matching. At this equilibrium, in period 7 firm j makes an exploding offer to the applicant of quality j+1, who accepts that offer.

The intuition is as follows. If all firms make offers in period 7, a firm j will make an early (t<7) exploding offer to an applicant only if the applicant has an expected quality of j+1 or higher.[14] However, an applicant with an expected quality of j+1 (or higher), has an expected profit from the optimal matching tomorrow that is higher than $j(j+1)$.[15] Hence no firm which deviates from the proposed equilibrium by making an offer in

[14] Early open offers will not help firm j to capture an applicant of expected quality higher than j+1. An applicant who receives an open offer will simply hold that offer, and only accept it if he does not receive a better offer. That is, along the equilibrium path, the applicant will accept firm j's offer only if he is of quality j+1 or lower.

[15] This is partly due to the fact that the profits of the applicants are convex in the applicants' quality (since the applicant receives the product of his quality, say k, times k+1).

period 1 will have an offer accepted that gives the firm a higher expected payoff than it receives at the equilibrium by waiting until period 7.[16]

Note that when the applicants are risk averse, they are willing to accept early exploding offers from firms of lower quality. However, when firms are risk averse, they will only make early exploding offers to applicants who are of even higher quality.[17]

Proposition 2: In the Open offer condition, there is a perfect Bayesian equilibrium with efficient late matching in which firm *j* matches to the applicant of quality *j*+1.

Proposition 3: In the Renege condition, there is a perfect Bayesian equilibrium with efficient late matching. At this equilibrium, in period 9, firm *j* makes an exploding offer to the applicant of quality *j*+1, who accepts that offer.

The intuition is essentially the same for the open offer and the renege case. In the open offer case, a firm *j* has no incentive to make an early offer, as an applicant will not accept, but merely hold the offer. This means the firm simply offers an option to the applicant, which can be redeemed if the applicant receives no better offers, and such a strategy is dominated by one in which the firm waits until period 7 before making any offer.

All three treatments allow for equilibria with early matchings, and all have a perfect Bayesian equilibrium with late matching. The set of weakly dominated strategies of applicants is however different in the 3 treatments.

In particular, since a strategy is a function that specifies an agent's actions at each of his information sets, we can (even in the renege condition) speak of an agent as adopting a strategy of "locking in" an offer at some point of any of the experimental

[16] The fact that we have one more applicant than firm is crucial, as in the case of 5 firms and 5 applicants, there would still be an early matching perfect Bayesian equilibrium. For a general account of how early matches result from comparable demand and supply see Niederle, Roth and Ünver (in preparation).

[17] For models that study risk aversion and mutual insurance is the reason for (ex ante efficient) unraveling, see Li and Rosen (1998), Li and Suen (2000) and Suen (2000). In our model it is easy to see that the market would unravel, if, say applicants received a payoff of -1000 for remaining unmatched. For a more precise intuition, see our discussion on the robustness of the late matching in the exploding offer case below.

treatments by accepting (and not just holding) the offer, and not later reneging on it. We can now state the following.

Proposition 4:

In the open offer and the renege treatment, it is a weakly dominated strategy for applicants to lock in firms early, before period 7. (Applicants always do at least as well, and sometimes better, if they hold the best offer they have received, or remain willing to renege on their acceptance, respectively, as long as better firms remain unmatched.) In the exploding offer treatment, it is not a weakly dominated strategy for the applicant to accept an exploding offer early (before period 7), which means it is not a weakly dominated strategy to lock in a firm early, before period 7.

This may imply that the firms' behavior may be different in the different conditions. In the case of exploding offers and binding acceptances, (risk neutral) firms are always prepared to make early offers to applicants who have an expected quality that is higher than the one the firm receives in the stable match.[18] In the open offer and renege condition, firms are not prepared to make any early offers, as applicants would simply use the offer's option value, which can only reduce the firms' profits.

This difference may affect the robustness of the various equilibrium refinements to deviations from equilibrium, e.g. to random or other non-equilibrium behavior of some participants. For example, suppose there are some applicants who do not want to reject offers without a better offer in hand.

In the case of exploding offers and binding acceptances, such applicants will accept early (exploding) offers. This implies that firms will have an incentive to make early offers to applicants with an expected quality higher than the firms' equilibrium match and there will be early matchings in such markets.

Furthermore these early matched applicants (and firms) impose a negative externality on (higher quality) firms that do not make an early offer, but which may want to hire them later on. The reason is that these applicants irreversibly accepted an early

[18] In the late matching equilibrium, applicants have to reject such offers.

offer from a lower quality firm. If this negative externality is high enough, high quality firms also start making early offers (to applicants whose expected value is *lower* than the quality they would receive in an assortative match in period 7), only to prevent high quality applicants from being captured early by low quality firms. These early offers are in turn accepted by rational applicants as well, which implies that an even bigger portion of the market moves early. So, a few applicants who do not reject early offers can affect the incentives of all firms and applicants, such that matching late is not an equilibrium any more. By this mechanism a few applicants can affect the timing of a much bigger portion of the market, and cause the market to transact early.[19]

In contrast, in the open offers and renege treatment, applicants who do not want to reject offers (without having another offer in hand) can merely hold on to the offer, and use it as an option. Such applicants would not differ from rational applicants, who would also use the option value of an offer. So, in the open offers and renege treatments (and again, in contrast to the exploding offer treatment) even when faced with these kinds of applicants, firms do not benefit from making early offers, and indeed have a strict incentive *not* to make early offers. Furthermore suppose there were a few applicants who would not only hold, but accept early offers in the open offer treatment, or never renege upon accepting an early offer in the renege treatment, that is applicants who "lock in" an offer early. Since other applicants would still use firms' early offers as an option, the incentives for firms to make early offers are nonetheless considerably weaker than in the exploding offer case.

Thus, each of the treatments has multiple equilibria, including a perfect equilibrium with efficient late matching. However, the late matching equilibrium appears to be less robust in the exploding offer (with binding agreements) treatment, than in both the open offer and renege treatment.

This is reflected by the fact that for both the open offer and the renege treatment, iterated elimination of weakly dominated strategies leaves only strategies in which firms make offers only after the applicants' qualities are fully revealed. This is also true if the

[19] However, it cannot be the case that in a pure strategy equilibrium all firms match before the uncertainty is resolved, as then, for example, the worst firm among the ones that make offers in the last period in which there are unmatched firms would have an incentive to not make the offer, and rather hire the best of the remaining 2 applicants once the uncertainty is resolved.

applicants do not reject offers without having received a better offer. In the exploding offer treatment, in contrast, iterated elimination of weakly dominated strategies does not in general preclude early matching (see the example in the appendix).

Proposition 5:

All strategies that survive iterated elimination of weakly dominated strategies in the open offer treatment are ones in which no firm makes an offer before period 7, and in period 7, 8 or 9 each firm *j* makes an offer to applicant of quality *j*+1. Applicants hold the best of all offers they receive before period 7 (applicants can accept the offer of a firm if it is the firm of highest quality that is still unmatched).

Proposition 6:

All strategies that survive iterated elimination of weakly dominated strategies in the renege treatment are ones in which no firm makes an offer before period 7, and in period 7, 8 or 9 each firm *j* makes an offer to applicant of quality *j*+1. Whenever an applicant receives a better offer than the one he has already accepted, he will renege on his former acceptance.

IV. The Experimental matching markets

We explore in the laboratory the environment described in the previous section. The qualities of firms are simply their assigned ID number (from 1 to 5), the qualities of applicants are revealed over time.

Treatment 1: Exploding and Open offers

Each firm can decide whether to make each offer open or exploding. Once an applicant accepts an offer, the acceptance is binding, and firms cannot make subsequent offers to an applicant who has already accepted an offer.

Treatment 2: Open Offers Only

Firms can only make open offers. Once an applicant accepts an offer, the acceptance is binding, and firms cannot make subsequent offers to an applicant who has already accepted an offer.

Treatment 3: Renege

In this treatment, firms can again decide whether to make open or exploding offers. However, an applicant who accepted an offer may still receive further offers. An applicant can renege on initial acceptances and accept a new offer at a cost of 1 point (that is subtracted from his final payment).

We conducted 7 sessions of the exploding offer treatment, and 6 sessions of the open offer and 6 of the renege treatment. Subjects participated only once. Participants kept their role, firm or applicant, for the whole experiment, and, for firms, also the firm ID and hence quality (from 1 to 5). The experiment was conducted at the Harvard Business School, with students, using z-Tree software (Fischbacher, 1999). Firms 1 and 2 received an additional amount of $5,[20] and each participant received $0.10 for each point earned. All participants received a $10 show up fee.

V. Results of the Experiment: Unraveling, Efficiency and blocking pairs

First we investigate whether different rules concerning exploding offers affect the timing of the market. How long do firms wait to extend offers, and hence how much information about an applicant's quality do firms have when extending the offers that were eventually accepted? Since in all our treatments firms could make open offers, the time at which an offer was made doesn't necessarily correspond to the time at which an offer was accepted. Therefore we first concentrate on the period in which final offers, i.e. offers that were eventually accepted, were extended. We will later examine the timing of acceptances.

[20] The instructions stated that some participants, already determined in advance, would receive some additional fixed payment (see instructions).

A market experiences no unraveling if final offers are all made after period 7, once all the uncertainty about applicants' qualities is resolved. In our experiment subjects participated in 20 markets. Figure 1 shows the timing of final offers for all treatments over all 20 markets. The timing is presented in terms of how many signals had been revealed before the offers were made. So a value of 1 corresponds to offers made when only one signal was available (periods 1-3), 2 denotes offers made after 2 signals, i.e. offers made in periods 4-6, and 3 signals corresponds to the final quality of applicants being known, that is offers made in periods 7-9. For the renege treatment, we only consider an offer to be final if it was accepted and not reneged upon. The results are presented in blocks of five markets.

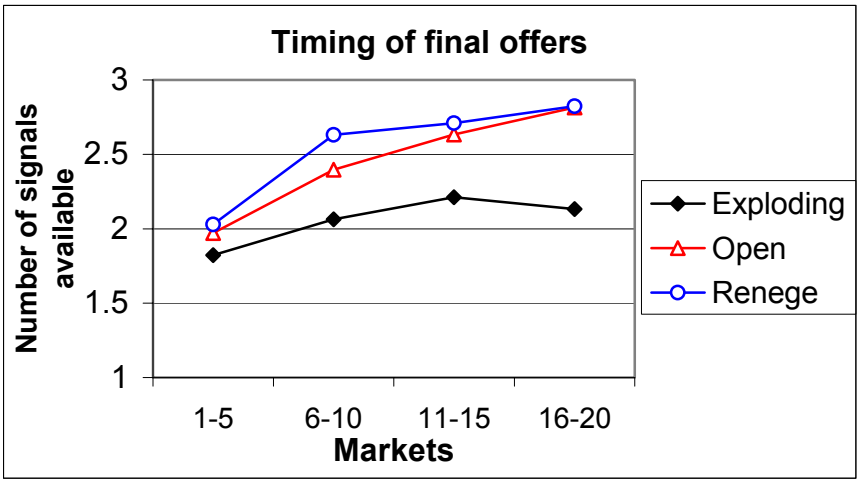


Figure 1. For each treatment, the time at which final offers were made (i.e. offers that eventually result in a match).

The first 5 markets in all treatments look similar, there is no significant difference in the average number of signals observed before firms make their final offers (that is offers that result in a match). A two sided Mann Whitney *U* test on session averages on the average number of signals observed when making a final offer in the first five markets, gives *p* values of 0.63 when comparing Open to Renege (n=12), 0.32 when comparing Renege to Exploding (n=13) and 0.316 when comparing Open to Exploding (n=13). However, as participants gain experience, matches come to be made later in the open offer and the renege treatments, but not in the exploding offer treatment. In the last five markets (markets 16-20), final offers in the exploding offer treatment are made with significantly fewer signals than in the renege treatment (p = 0.003, n=13) and the open

offer treatment (p = 0.003, n=13),[21] while the renege and the open treatment are not significantly different (p = 0.63, n=12).

We now investigate the timing of offers in more detail. Figure 2 shows, for each treatment, in the last five markets, the percentage of offers that were made when one, two or all three signals (3 signals = final quality) about the applicants' quality were available.

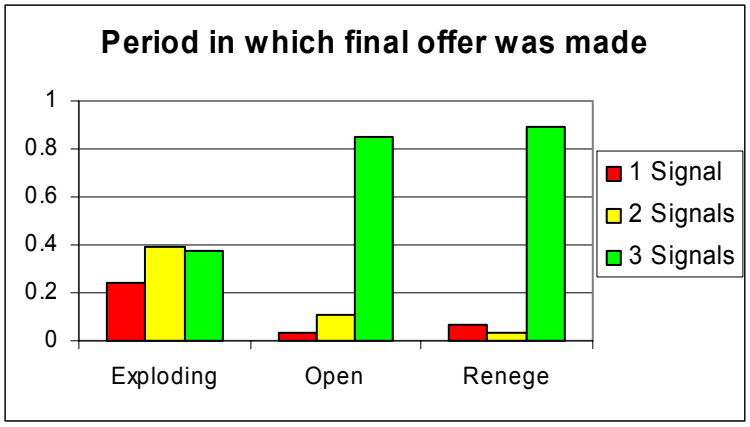


Figure 2. For each treatment, in the last five markets (markets 16-20), the proportion of offers that were made when one, two or all three signals (and hence the final quality) about applicants' quality were available.

Like Figure 1, Figure 2 shows that unraveling occurs when firms can make exploding offers and acceptances are binding. When firms are forced to make open offers, or when applicants can renege on their acceptance, the markets experience almost no unraveling. Open offers and the applicants' ability to renege also help a market to defer the timing of contracts, even when the market begins with early appointments (as in the first five markets of Figure 1).

The fact that the open offer treatment and the exploding offer treatment are so different, suggests that firms make exploding offers when they are given the opportunity to do so. Indeed, in the last five markets of the exploding offer treatment, only firm 1 makes an open offer in more than 10% of the markets (while firm 5 makes no open offers at all).

[21] Furthermore, we can compute for each of the last five markets in any session the average number of signals the five firms had when making their final offer. The exploding offer market with the *highest* such number (that is, the one where on average the five firms saw the most signals before making their final

Except for firms 3 and 4, every firm made an exploding offer in every one of the last five markets in each of the seven sessions of the exploding offer treatment (and firms 3 and 4 made exploding offers in 34 of these 35 markets). In the renege treatment, firms make somewhat more open offers, but the vast majority of firms (at least 67%) make an exploding offer in each of the last five markets.

Thus when firms could make open and exploding offers, the majority of offers were exploding. Firms made use of their ability to make exploding offers to put pressure on applicants. However, this effect was more pronounced when acceptances were binding. When applicants can renege on their acceptance the value of making an exploding offer is smaller, and firms made less use of that option.

Figure 3, which shows the timing of final offers for firms 4 and 5 only (in the last five markets) for each treatment, shows an even clearer difference among conditions than Figure 2. This means that the unraveling in the exploding offer treatment is to a large extent driven by firms 4 and 5, the high quality firms, which, in the open and renege treatment predominately hire applicants after all the information is known.

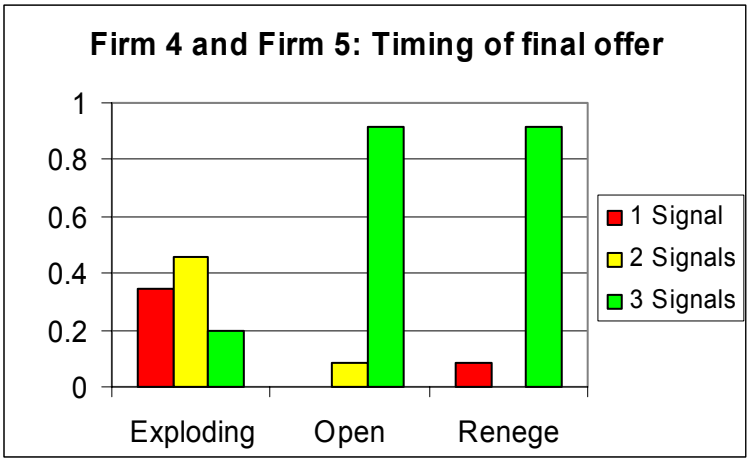


Figure 3a. For each treatment, in the last five markets, the proportion of final offers that were made when one, two or all three signals (and hence the final quality) about applicants quality were available, by firms 4 and 5 only.

offer), is lower than the market with the *lowest* average number of signals used by the five firms in any of the last five markets in any session of either the open or the renege treatments.

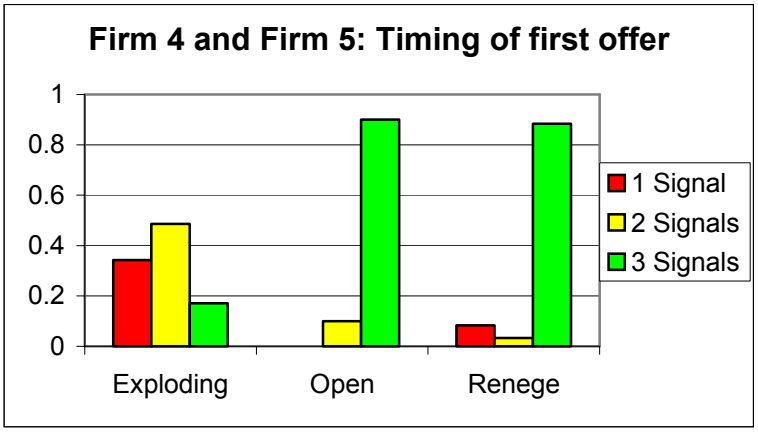


Figure 3b. For each treatment, in the last five markets, the proportion of *first* offers that were made when one, two or all three signals (and hence the final quality) about applicants quality were available, by firms 4 and 5 only.

For firm 4 and firm 5, the final offer corresponds mostly to the first offer made.

In the exploding offer treatment, lower quality firms also make early offers, but their offers are much more often rejected. In the open offer and renege treatment, firms of all qualities wait for more information on applicants, before making their first offer. This results in first offers also being extended mostly when there is complete information about applicants' qualities.

Transaction Times:

So far we examined the timing of offers averaged across different markets, now we explore the timing within markets. A transaction is made (and announced to the market) only when an offer is accepted. The following table shows for each treatment the timing of first acceptances in the last five markets (where we use only final acceptances that were not reneged upon for the renege treatment).

	1 Signal (1-3)	2 Signals (4-6)	3 Signals (7-9)
Exploding	.71	.29	0
Open	0	.23	.77
Renege	.30	.10	.60

Table 1: For each treatment (in the last five markets) the proportion of markets whose first acceptance (which as not reneged upon in the renege treatment) was made when only one signal, 2 signals, or 3 signals (and hence the final quality) about applicants' quality were available.

Markets with exploding offers not only experience early contracting on average. 71% of the markets have their first acceptance with only signal 1 available. All 35 markets (the

last five markets of all 7 sessions of the exploding offer condition) have their first acceptance before the final quality of applicants becomes available. In contrast, when firms can only make open offers, or when acceptances by applicants are not binding, 77% and 60% of the markets, respectively, experience their first acceptance only after all the uncertainty about applicants' quality is resolved.

Even though markets with different rules concerning exploding offers experience a difference in timing of the first accepted offer, their *last* accepted offer is predominately in periods 7-9. In the open and renege treatment, not a single market (of the last five markets) ends before period 7, and in the exploding offer treatment, 89% (31 out of 35) of the last five markets finish after period 7. Note that, in each treatment, the last firm to be unmatched has strong incentives to wait and see which of the two remaining applicants is of higher quality. Thus it is unsurprising that at least one offer is made after period 7 (since it will often be the case that at least one firm remains unmatched after period 6, even when firms try to match early).

What are the costs of unraveling?

From this point on, we eliminate from our main analysis one outlier session of the renege treatment. In that particular session there was one applicant who *never* accepted an offer. No other applicant in any session of any treatment behaved in this way. In footnotes we will show the analysis that includes all renege sessions.

We have seen that the market unravels when firms can make exploding offers and acceptances are binding. Now we investigate the costs of unraveling. We evaluate the different treatments according to the quality of the resulting matches. How much use do firms make of the information about applicants that becomes available over time? We consider three benchmarks: assortative matching when only signal 1 is available, assortative matching with 2 signals, and assortative matching once all the uncertainty about applicants' qualities is resolved (the efficient outcome). That is, we compare the efficiency of the observed market outcomes with the most efficient match that could have

been achieved using only the information in signal 1, in the first two signals, and when all three signals are available.

We calculate the value of the assortative match after the 1st signal by producing an assortative match between firms and applicants according to the applicants' first signal. We use the actual quality of applicants determined during the experiment to compute the value of this match. In case of ties in the first signal between two applicants, we take the average of the two possible outcomes. The value of the assortative match with 2 signals is computed analogously. Let "1 Signal" and "2 Signals" denote the value of the assortative match after the first and after the second signal respectively, and "Efficient" the value of the unique stable and efficient match once all signals are known. Figure 4 shows the averages across sessions and markets of (Actual Profits – 1 Signal)/(Efficient – 1 Signal), and (Actual Profits – 2 Signals)/(Efficient – 2 Signals).

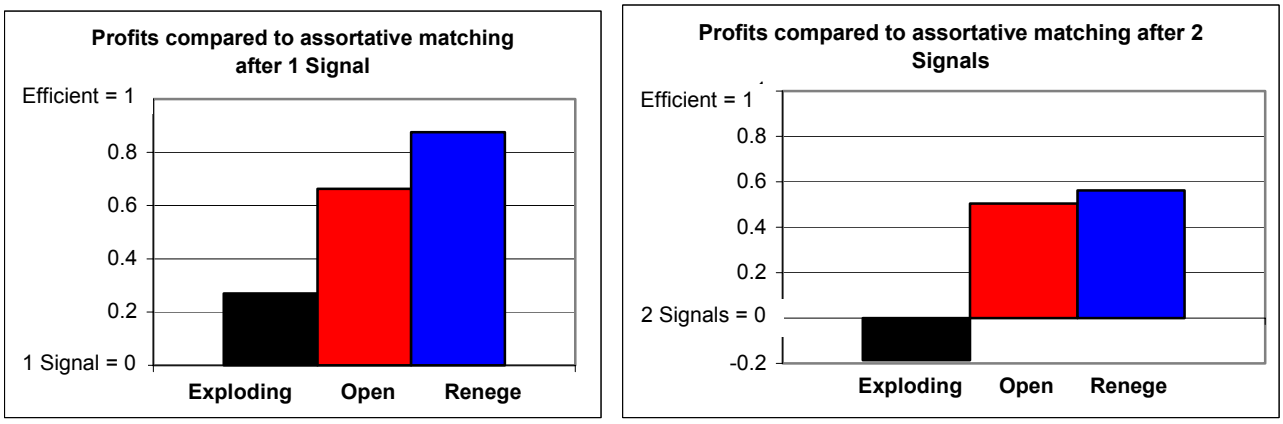


Figure 4a and 4b. 4a shows for each treatment the value of (Actual Profits – 1 Signal)/(Efficient – 1 Signal) averaged across sessions. That is it shows the relative gains of the actual match towards efficiency compared to assortative matching after 1 signal. Figure 4b shows the similar results for 2 signals.

Figure 4a shows that all treatments achieve on average a social surplus higher than assortative matching with one signal. Efficiency gains are significantly lower in the exploding offer treatment than in the open (p=0.063) and the renege treatment (p=0.004).[22] The renege treatment achieves significantly higher gains than the open offer

[22] When we include the outlier session in the renege treatment, the value of the proportion of gains from assortative matching after one signal towards efficiency is 0.69 (instead of 0.88). The exploding offer treatment still achieves significantly lower proportionate gains in efficiency starting from the assortative match after 1 signal than all the sessions in the renege treatment: p=0.032.

treatment (p=0.045).[23] Assortative matching based on 2 signals (the second signal becomes available at period 4) would have resulted in a higher efficiency than the exploding offer treatment, but both the Open and Renege treatment achieve higher efficiency levels than assortative matching after two signals. Furthermore, both the open offer and renege treatment achieve significantly higher efficiency gains than the exploding offer treatment (p=0.007 and p=0.06[24] respectively), while they are not significantly different from each other (p=0.465). When we look at absolute efficiency levels, the efficiency of the exploding offer treatment is significantly lower than of the open treatment p=0.03 and the renege treatment p=0.009, while the renege and the open offer treatment are not significantly different p=0.116 using a two sided Mann-Whitney U test with session averages. [25] [26]

A different way to measure the functioning of a market is to ask how many participants, who are currently not matched to each other, would both prefer to be so, instead of remaining with their current match (or being unmatched). A firm and a worker in such a position are called a blocking pair to the current match. We consider potentially "disruptive" blocking pairs that involve at least one matched player. These are blocking pairs that would disrupt the outcome of the market, had they the chance. (Blocking pairs that simply involve unmatched participants are much less disruptive, and in naturally occurring markets they often have a subsequent opportunity to match to one another.) The next table shows, for the last five markets of each treatment, the average number of disruptive blocking pairs in each market. In the exploding offer treatment, there are significantly more blocking pairs than in both the open (p=0.003) and renege treatment

[23] When we include all renege sessions, the p-value is p = 0.2.
[24] When we include all renege sessions, the value of the proportion of gains from assortative matching after two signals towards efficiency is 0.14 (as opposed to 0.56). The p-value when we include all renege sessions is p = 0.25.
[25] All treatments achieve high levels of efficiency (compared to the alternative of no firm being matched). The efficiency in the exploding offer treatment is 93% compared to 96% in the open offer treatment and 98% in the renege treatment. However, even a random allocation of the six applicants to the five firms achieves an efficiency of 75%. Average efficiency of assortative matching after one signal is 88% and after two signals it is 93%. We'll see below that even small changes in efficiency can be associated with big changes in payoffs to differently ranked participants.
[26] When we include all renege sessions, the comparison with the exploding offer treatment has a p-value of 0.07, the comparison to the open offer treatment yields p = 0.37.

(p=0.004).[27] In the exploding offer treatment, in each market, there are, on average 3 (firm, applicant) pairs that would rather be matched to each other than to their current partner. In the open and renege treatment, there is on average only one such pair per market. The maximum feasible number of disruptive blocking pairs is 15.[28]

Number of disruptive blocking pairs

Exploding	Open	Renege
3.06	1.03	0.56

Table 2: Average number of disruptive blocking pairs in each treatment in the last five markets involving matched applicants.[29]

Individual level consequences of unraveling

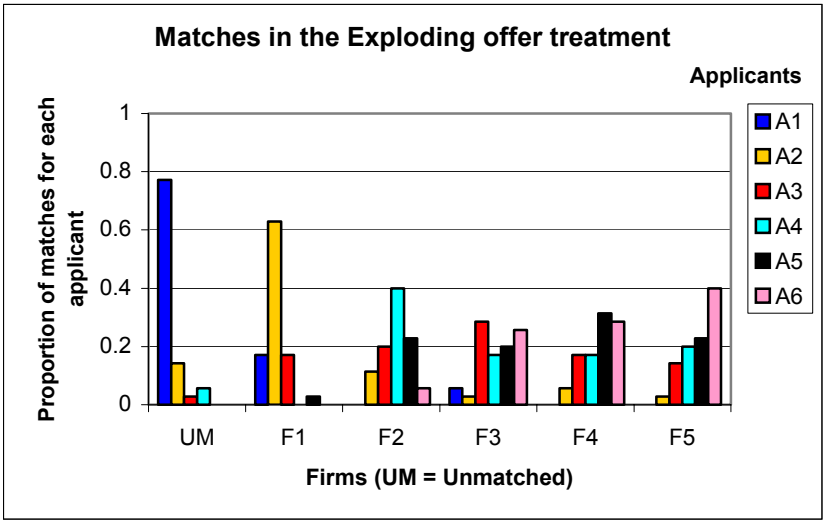
We have seen the loss of social surplus when firms can make exploding offers that are binding, compared to when offers have to be open or applicants can renege on their acceptance. Now we investigate the value of the match for each applicant and each firm separately, for the last five markets of each treatment. The following figures show for each treatment, which applicant was (on average) matched to which firm. The efficient and only stable match is the one at which firm 5 hires applicant 6, firm 4 hires applicant 5, and so on, with firm 1 hiring applicant 2 and applicant 1 remaining unmatched.

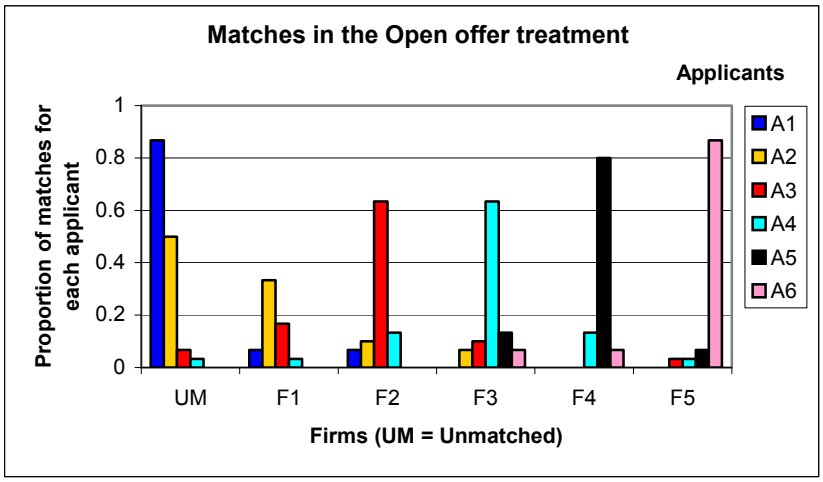
The exploding offer treatment is far from reaching an assortative match. In the Exploding offer treatment, higher quality firms do match to higher quality applicants, and vice versa, but only barely so. Figure 5 makes clear the contrast with the other two experimental conditions, in which nearly efficient sorting takes place.

[27] The open offer and renege treatment, do not differ significantly in the number of blocking pairs (p = 0.2245). When we use all the renege sessions, the p-values are 0.002 and 0.46, when comparing it to the exploding and open treatment respectively.

[28] The highest number of blocking pairs using only matched applicants, namely 15, is achieved by anti-assortative matching. Then the matched firm 5 generates 5 blocking pairs (4 of which use matched applicants), firm 4 generates 4, firm 3 generates 3, firm 2 generates 2 and firm 1 generates only 1.

[29] When we include session 2-2, then the renege treatment has on average 0.8 blocking pairs involving matched participants.





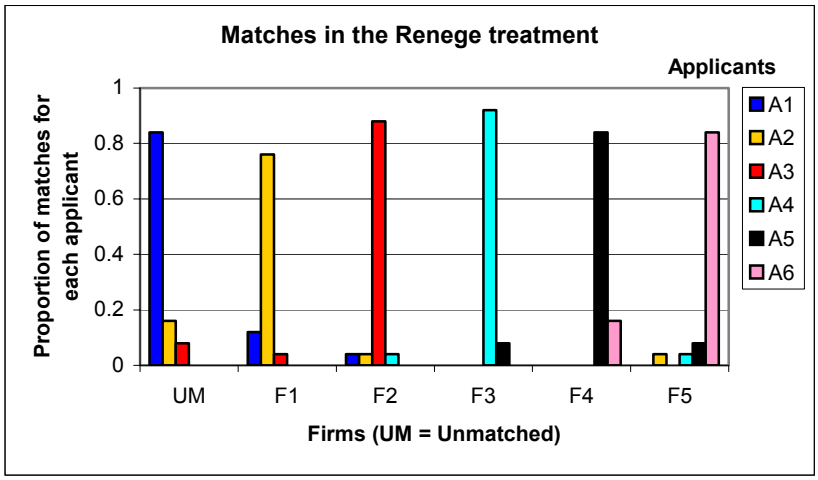


Figure 5: For each treatment, in the last five markets, for each firm the proportion of applicants of each quality this firm hired. UM shows the proportion of applicants of each quality that remain unmatched.

The Firms

The following graph shows for each firm the average quality of the applicant they are matched to and the average quality of the applicant that remains unmatched.

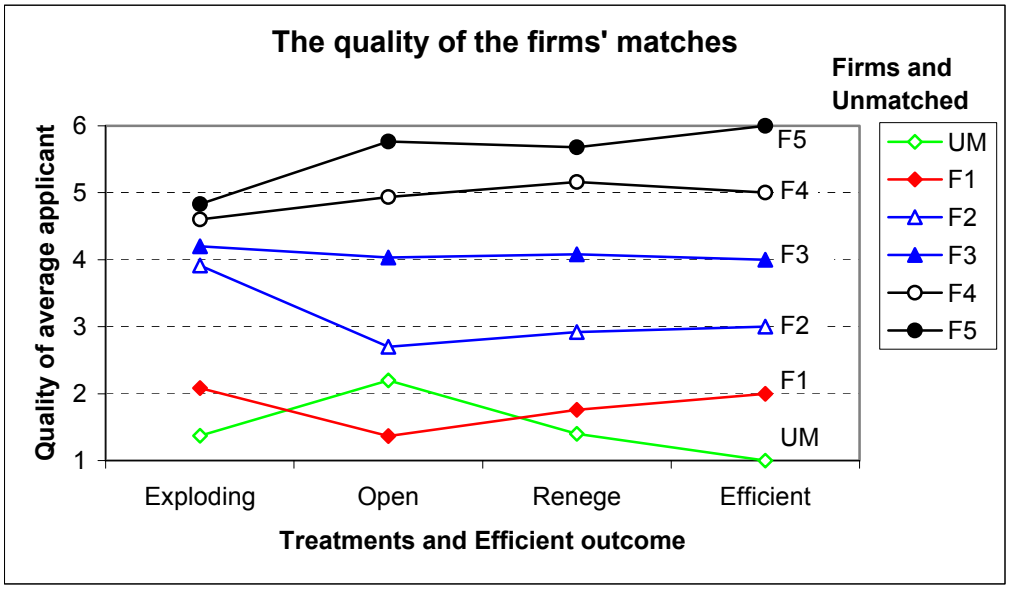


Figure 6: The average quality of the applicant each firm is matched to in the last five markets of each treatment. UM shows the quality of applicants who remain unmatched. Efficient shows for each firm the quality of the applicant in the unique stable and socially efficient match.

The exploding offer treatment significantly lowers the payoff of the highest quality firm, firm 5, by 16% compared to the open ($p = 0.0056$) and by 15% compared to the renege ($p = 0.046$) treatment. But the low quality firms, firm 2 and firm 1, achieve a significantly *higher* payoff in the exploding offer treatment, compared to the open offer treatment ($p=0.062$ and $p=0.07$ for firm 2 and firm 1 respectively) and the renege treatment ($p=0.001$ and $p=0.099$).[30] In the exploding offer treatment, firm 2 gains 45% compared to the open offer and 34% compared to the renege treatment.

The difference in the quality of applicants between firm 2 and firm 5 is 0.92 in the exploding offer treatment, which is significantly lower than in the open offer treatment, 3.07 ($p=0.0025$) and the renege treatment, 2.76 ($p=0.026$).[31][32]

[30] When we include all renege sessions, the p-values for firm 5, when comparing the exploding offer to the renege treatment is $p=0.023$, while it is $p=0.025$ for firm 2 and $p=0.05$ for firm 1.
[31] When we include all renege sessions the p-value is $p = 0.014$
[32] In all treatments higher quality firms hire higher quality applicants, on average, but not in each session.

The Applicants

The following table shows for each applicant the average quality of the firm they are matched to in the last five markets for each treatment.

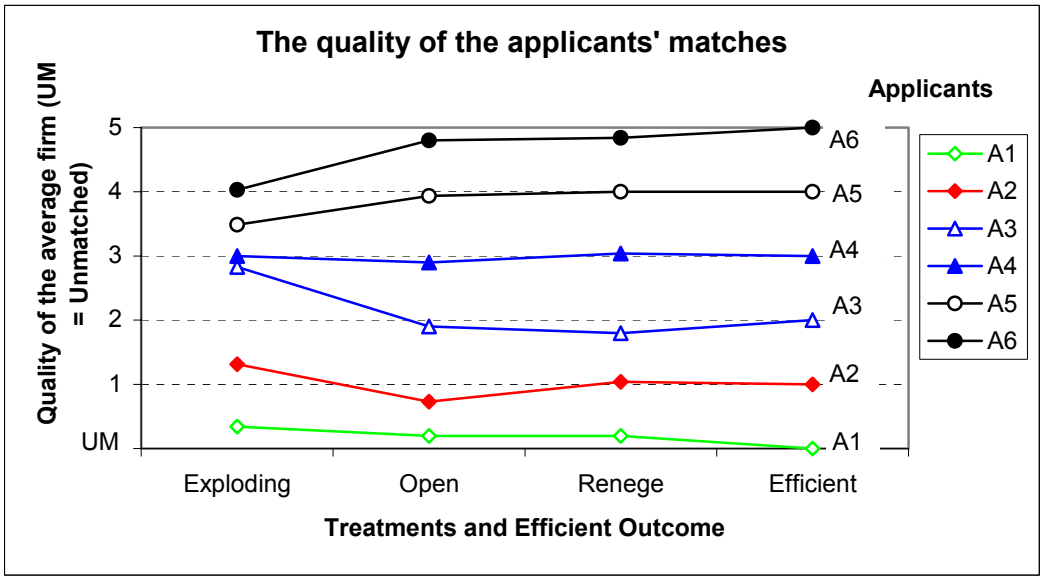


Figure 7: The average quality of the firm the applicant is matched to in the last five markets of each treatment, where UM is unmatched. "Efficient" shows for each applicant the quality of the firm in the unique stable and socially efficient match.

As for the firms, it is the high quality applicants, applicant A6 and A5 that receive a significantly lower match in the exploding offer treatment than in the open offer treatment (by 10% and 11% with p=0.045 and p=0.049 for firm 6 and 5 respectively) and the renege treatment (by 17% and 13% with p=0.019 and 0.023). And it is a medium quality applicant, applicant 3, who significantly gains from unraveling (by 49% and 57% with p=0.026 and 0.041 compared to the open and renege treatment respectively).[33] In all treatments higher quality applicants are hired by higher quality firms, on average. The difference in the quality of firms between applicant 3 and applicant 6 is 1.2 in the exploding offer treatment, which is significantly lower than in the open offer treatment, 2.9 (p=0.0034) and the renege treatment, 3.04 (p=0.0044).[34]

[33] When we include all renege sessions, the p-values are for firms 6, 5 and 3: p=0.009, p=0.108 and p=0.037 respectively.

[34] When we include all renege sessions, the *p*-value is $p = 0.0026$.

The inefficient matchings in these markets are costly for the high quality firms and applicants, while low quality firms and applicants tend to gain from early matches.

Congestion

So far we focused on the average quality of applicants matched to specific firms. Now we investigate the number of matched and unmatched applicants (and firms). This will also be the starting point to investigate reasons for unraveling in the exploding offer treatment, namely whether it is driven mostly by the need to avoid congestion in the final periods. We say that a market is congested if some firms are unmatched because they run out of time to make offers that they would have liked to be able to make. (See Roth and Xing, 1997, for a study of endogenous congestion in an open-offer market for clinical psychologists.) In a market like this one, in which all matches are profitable, congestion could nevertheless cause some firms to be unmatched.

In the exploding offer treatment, in the last five markets, no firm is ever unmatched. In the renege treatment, in the five sessions and five markets, firm 1 is unmatched twice, that is 1.6 % of firms fail to match.[35] In the open offer treatment, 9.3 % of firms are unmatched (firm 2 is unmatched twice and firm 1 twelve times – out of 30 markets with 5 firms each), which is significantly higher than in the exploding (p= 0.043) and renege treatment (p=0.047).[36]

To start understanding why open offers lead to so many more unmatched firms than when firms can make exploding offers and also when applicants can renege on their acceptance, we investigate the timing of acceptances of offers. (In the renege treatment, we only consider acceptances that were not reneged upon).

[35] We continue to exclude session 2-2 of the renege treatment, as we had one applicant who *never* accepted any offer, which resulted in a session with an unusual number of unmatched firms, namely 1.2 on average in the last five markets.

[36] When we include all renege sessions the difference is not significant any more, the p-value is 0.217.

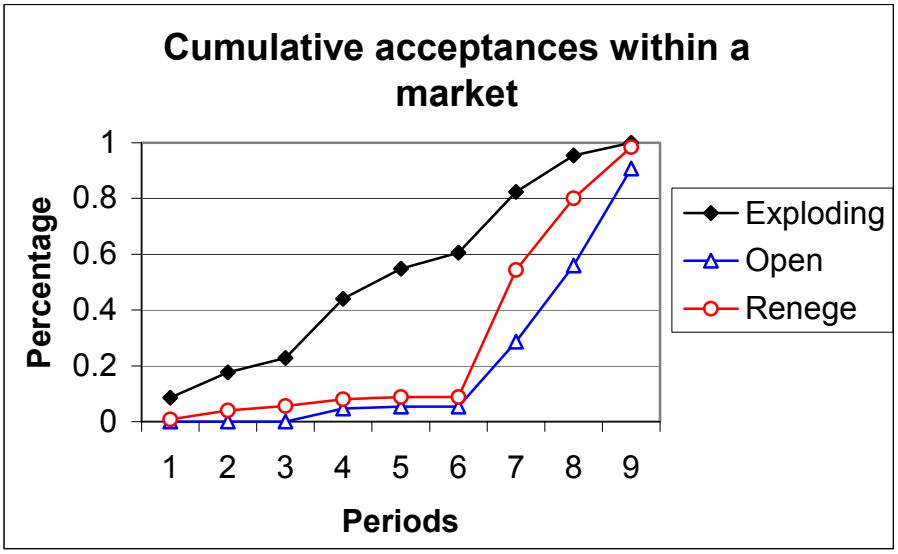


Figure 8: For each treatment, for the last five markets, the average number of final acceptances up to the end of each period.

In the exploding offer treatment about 60% of firms are matched by the end of period 6, while 54% are matched by the end of period 7 in the renege treatment. In the open offer treatment it takes an additional period to reach this level, only by the end of period 8 are 56 % of firms matched. That is, on average, in the open offer treatment, more than 2 firms still have to match in the last period. One possible explanation for the difference in timing of acceptances is that applicants can hold offers in the open offer treatment, while they have to accept offers that are exploding in the renege treatment.[37] However, the fact that on average 0.46 firms remain unmatched implies that not all firms in the open offer condition made offers to applicants who eventually accept their offer.

Another difference between the open offer treatment, and the renege treatment, has to do with the fact that market participants are informed when an offer is *accepted*, but not when an offer is made. In the open offer treatment, an applicant who waits for a better offer has to hold his offer while waiting, while in the renege treatment, if an applicant receives an exploding offer, he has to either accept or reject that offer and can then wait for better offers to come along. Thus the information available to firms is different in the open and renege treatments. In the open offers treatment the firm will not make offers to matched applicants, but may waste one of her few remaining offers on an applicant who

[37] We have seen that most firms in the renege treatment use exploding offers.

is already holding a better offer. In the renege treatment, once an applicant accepted an offer from a given firm, all firms of lower quality can tell that they should not waste an offer to try to match to this applicant in the last 3 periods of the market.

This difference in information adds congestion to the open offer treatment, in which firms cannot avoid wasting some offers. On average, in the last five markets, in the renege treatment, all firms together make an average of 5.6 offers in the last 3 periods of the market. In the open offer treatment, firms make about the same number of offers, on average 5.53 offers. In the renege treatment, only 0.07 offers are wasted on average, in the sense that the applicant already has an offer from a higher quality firm. In the open offer treatment, 0.93 offers are wasted on average, that is almost one offer per market. This difference is significant ($p=0.049$).[38]

While the open offer treatment and the renege treatment experience differences in timing of acceptances and differences in the number of firms that match, the exploding offer treatment and the renege treatment only differ in the timing of acceptances.

Note that the renege treatment experiences virtually no endogenous congestion, and that on average only 5.3% of firms are matched by the end of period 6. That is, when firms can make exploding offers, 3 periods are enough for the market to clear. However, in the exploding offer treatment, by the end of period 6, 60.5 % of firms are already matched. It appears that the reason for unraveling in the exploding offer treatment is thus not anticipated congestion.

A further piece of evidence for strategic causes of unraveling comes from examining the length of the market, i.e. the timing between the first and the last acceptance. In the exploding offer treatment, 32 out of 35 markets last for 5 or more periods (with 10 lasting exactly 5 periods). In the open offers only and the renege treatment, the first final offers are made later, and the markets also last for a shorter time. In the renege treatment, 40% of the markets last for 5 or more periods, and for the open offer treatment, the number is 23%.

[38] When we include all renege sessions the p-value is 0.0032.

The fact that the markets in the exploding offer treatment last so long shows that unraveling in this treatment is not caused simply by a desire to avoid congestion. Instead, as the theory outlined earlier suggests, inefficiently early offers appear to result from the strategic opportunity presented to middle quality firms to use exploding offers to their advantage when there are applicants who are inclined to accept them, and when these acceptances are binding.

VI. Discussion

In this paper we examine the effects of market culture.[39] First we discussed a range of observations of natural markets, focusing particularly on the markets for undergraduate admissions and graduate studies. Next we developed some simple theory to organize the experiment that followed. The results of the experiment confirmed the hypothesis motivated by the natural markets—exploding offers with binding acceptances are potent in causing inefficiently early matching. This was so even in an experimental environment in which the efficiency gains from late matching were sufficient to support late matching at a perfect equilibrium, even in the exploding offer condition (in which the late matching equilibrium, although perfect, was fragile).

We observed that a striking feature of many markets is that market participants spend a good deal of effort addressing how and when offers are made, accepted, and rejected. The formal and informal rules, customs, and norms that result, are a critical element of the widely different ways that the matching processes in these markets are organized. In some markets, exploding offers are the norm, and applicants for positions find themselves faced with offers that must be accepted or rejected before other offers may be considered or even received. In others, exploding offers are discouraged, or made more difficult to use to advantage. Because these many markets (e.g. those mentioned in Table 1) are quite different from one another in other respects also, it is natural to look to the

[39] We remain agnostic about the *causes* of different market cultures, although we think that the evidence from undergraduate admissions—in which different offer and response cultures operate at different times--and other markets suggests that market culture cannot always be deduced from the organization or conditions of the market.

laboratory for an investigation that seeks to isolate the effects of different rules and customs concerning exploding offers.[40]

In our experiment, we see that firms choose to make early exploding offers when the rules allow them, and when applicants' acceptances are binding. In consequence, in this condition of the experiment we see inefficiently early contracting, lower profits, and a higher number of blocking pairs.[41] Both the possibility for firms to make exploding offers, and binding acceptances of applicants are necessary for that outcome. Eliminating either of these yields a market in which matches are made later, with more information, which results in increased efficiency and fewer blocking pairs.

The problem facing applicants who receive early exploding offers when acceptances are binding is that, to reject such an offer, an applicant must hope for a better offer later in the market, hence hope not only that he will be highly ranked in the later market, but also that high quality firms do not fill their positions early. Once some applicants are ready to accept early offers, they impose a negative externality on high quality firms, making the whole market move early. We have seen in other environments that in order to successfully halt unraveling, a major factor is that applicants must be willing to reject early offers (Kagel and Roth 2000, McKinney, Niederle and Roth 2003, Unver 2001, Haruvy et al. 2002). When offers are open, or when applicants can renege on their acceptances, then the market does not have to depend on applicants' willingness to reject early offers to have most of its transactions happen efficiently late. This is why such markets work more efficiently.

The laboratory environment makes it easy to manipulate these factors. In naturally occurring markets, making it possible for applicants to renege on acceptances of early exploding offers involves a whole complex of behaviors; for example firms need to be willing to make offers to applicants who have already accepted exploding offers (recall

[40] Also, different rules and customs concerning how offers are made and received need not exhaust the reasons why markets differ in the incidence of exploding offers, etc. But in the laboratory, we can isolate the effect of different rules involving only how offers are made, and whether acceptances are binding, which in the natural markets that motivate this study appeared to be important variables.

[41] However some firms and applicants benefit from inefficient early matching (recall Figures 6 and 7), so it may not be easy to reorganize a market efficiently, once it has fallen into an early inefficient equilibrium.

e.g. the debate over rules for college admissions). This is one of the reasons that it is often difficult to model the detailed rules of a natural market, since they are typically a mix of formal and informal rules and customs. (And not all written rules are really obeyed, while some unwritten ones may be quite binding, which is what makes the study of markets such as those in Table 1 both challenging and fascinating.) Yet the results of the experiment have clear implications for many markets suffering from inefficiently early contracting.

For example, the market for clerks for Federal appellate judges has been suffering a serious market failure in which clerks have recently been hired two years in advance, i.e. at the beginning of the second year of law school (Avery et al. 2000). This is a market in which exploding offers are the mode, and in which verbal acceptances seem to be completely binding (law students are reluctant to renege on promises to Federal judges). In an effort to repair the market, in March of 2002, a large majority of Federal appellate judges voted to approve a proposal stating that "…the hiring of law clerks in the Fall after the first year of law school is an unacceptable practice," and that they therefore endorsed "a moratorium on law clerk hiring during the Fall of 2002…"[42], with hiring to resume only after Labor Day 2003, and be restricted to third year law students. While it is still to early to assess the short term effects of this attempt at market reform[43], some aspects of the proposal suggest that in the longer term the market may continue to unravel. In particular, the proposal calls for no changes in the market rules or customs, and in fact a FAQ accompanying the letter by Judges Becker and Edwards includes the following question and answer .

> "Q Are judges forbidden from making "exploding offers," i.e., offers that require an applicant to respond promptly to an offer?
> A The Plan does not purport to address how an offer is given by a judge. This is for each judge to determine. However, no applicant is obliged to act on an offer if the terms are unacceptable, nor is an applicant obliged to accept the first offer that he or she receives."

Given that law students are virtually never reported to renege on promises made to senior Federal judges (Avery et al 2000), the results of the present experiment give us a clear

[42] Letter to law school deans, March 11, 2002, signed by Chief Judge Edward R. Becker, and Judge Harry T. Edwards.

prediction: the problem of early contracting will not be solved by the current attempt at a one year hiring moratorium that leaves the market rules and customs intact. Rather, more fundamental changes in the market culture of judges and law clerks will be needed.[44]

More generally, many of the markets that have suffered market failures associated with early contracting and the unraveling of appointment times have attempted to fix these market failures with centralized clearinghouses. But there are many more markets that have not suffered these market failures, and are not organized in any centralized way. The present paper is meant to begin the investigation of the hypothesis that elements of market culture may play a critical role in the susceptibility of markets to these kinds of failures. Our results suggest that not only the "hardware" of the market, the applications, interviews, and centralized or decentralized clearing mechanisms are of concern. The detailed and sometimes informal rules and practices governing how offers are made, compared, and accepted or rejected are also a critical element of a market's design. That is, when it comes to market design, manners may be as important as machinery.

[43] Avery, Jolls, Posner, and Roth are conducting surveys of law students and judges in an effort to understand what happened in the Fall of 2003.

[44] On this point, see the discussion in Haruvy, Roth, and Unver 2002.

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Appendix:

To facilitate the presentation of the equilibrium strategies, we first introduce some notation.

Let σ be a permutation on (1,2,3,4,5,6), with $\sigma = (\sigma(1), \sigma(2), .., \sigma(6))$, where $\sigma(i)$ is the quality of applicant *i*, and let *S* be the set of all such permutations σ.

Let $p : S \to [0,1]$ s.t. $\sum_{\sigma} p(\sigma) = 1$ be a probability distribution over all possible outcomes, and let *P* be the set of all such probability distributions.

At any period $1 \leq t \leq 6$ let s_i be the sum of all signals that applicant *i* has received so far, s_{-i} the unknown signals the other applicants received, and let *r* be the remaining signal vector all applicants receive by period 7, so *s*+*r* is the sum of the signals, which determines relative quality.

If at period *t* applicant *i* already has signals s_i, the probability distributions on quality that are still feasible are $p^{s_i} \in P$ such that $p^{s_i}(\sigma) > 0$ if and only if there exist s_{-i}, *r* such that $\forall 1 \leq k, j \leq 6 : \sigma(k) > \sigma(j) \Rightarrow s_k + r_k \geq s_j + r_j$. Let P^{s_i} be the set of all such feasible probability distributions over outcomes p^{s_i}. Let $q \in P^{s_i}$ be the applicants' subjective belief about the distribution over outcomes.

For each player *i* let $p_x(i) = \sum_{\sigma:\sigma(i)=x} p(\sigma)$ be the probability that applicant *i* has quality *x* and let and $q_x(i) = \sum_{\sigma:\sigma(i)=x} q(\sigma)$ be applicant *i*'s beliefs about these probabilities.

Let F^M be the set of firms that are already matched and let $m(j)$ be the quality of the applicant matched to firm *j*.

Proof of Proposition 1 (late equilibrium in the exploding offer condition):

To specify the equilibrium we need to specify not only the strategies of the players, but also their beliefs at all information sets.

Firms and applicants believe that all unobserved offers are exploding offers, that is, they believe that no applicant holds an offer, and that all unmatched firms are able to make an offer.

At all information sets before period 7 in which no firm is matched, and at all nodes in period 7-9, the strategies of firms and applicants call for them to behave as follows:

In period $t<7$, no firm j makes an offer.

In periods 7, 8 and 9 the k-highest unmatched firm makes an exploding offer to the k-highest unmatched applicant.

The applicant holds the highest of all open offers he receives, and, in case he did not accept an exploding offer before, accepts the highest available offer in period 9.

In period 7 and 8, the (unmatched) applicant of the k-highest quality among all unmatched applicants, accepts any exploding offer from a firm whose quality is equal to or higher than the k-highest unmatched firm, and in case of receiving multiple offers accepts the highest one as long as he does not hold an open offer from a higher quality firm.

In periods $t<7$, suppose applicant i has received signals s_i so far and receives an exploding offer from firm j. The applicant believes that he is the only applicant to receive an offer, and that rejecting the offer has no impact on other applicants' behavior, as rejected offers are private information. The applicant forms as "favorable" beliefs as possible over the probability distribution of future qualities, and hence his expected payoff from rejecting the offer, that are consistent with receiving an offer from firm j. If there is no chance that firm j can do better by matching to applicant i than to wait for period 7 and match to the applicant of quality j+1, that is if $\left\{p : p \in P^{s_i} and \sum_{\sigma} p(\sigma)\sigma(i) j > j(j+1)\right\} = \phi$ then the applicant forms beliefs $q^{s_i} = \arg\max_{p}\left\{\sum_{\sigma} p(\sigma)\sigma(i)(\sigma(i)-1-j) \mid p \in P^{s_i}\right\}$, which maximize the difference between the expected profit of waiting and receiving in period 7 an assortative match, that is receiving $\sum_{\sigma} p(\sigma)\sigma(i)(\sigma(i)-1)$ and accepting firm j's offer and receiving $\sum_{\sigma} p(\sigma)\sigma(i) j$. If $\left\{p : p \in P^{s_i} and \sum_{\sigma} p(\sigma)\sigma(i) j > j(j+1)\right\} \neq \phi$ the applicant forms beliefs $q^{s_i} = \arg\max_{p}\left\{\sum_{\sigma} p(\sigma)\sigma(i)(\sigma(i)-1-j) \mid p \in P^{s_i} and \sum_{\sigma} p(\sigma)\sigma(i) j > j(j+1)\right\}$. The

applicant accepts the offer when $\sum_{\sigma} q^{s_i}(\sigma)\sigma(i)j > \sum_{\sigma} q^{s_i}(\sigma)\sigma(i)(\sigma(i)-1)$, otherwise he rejects the offer.

Suppose there is a match in period $t<7$. We assume that all unmatched firms and applicants believe that there are no outstanding open offers they are not aware of. The game consisting of the remaining firms and applicants starting from their current information[45] has at least one perfect Bayesian equilibrium, and we assume that players use the strategies of one of these for every such continuation game. We do not need to specify these strategies exactly (beyond that they are equilibrium strategies), because these strategies do not affect the payoffs of the firms and applicants who have deviated by matching, and hence do not affect whether they find it profitable or not to deviate.

We now verify that these strategies form a perfect Bayesian equilibrium.

Along the equilibrium path, all firms j make an offer in period 7 to the respective applicant of quality j+1. A firm j cannot profitably deviate by making an offer to j+2, or j, and applicant i of quality j+1 cannot profitably deviate by rejecting firm j's offer.

Along the equilibrium path: Assume all firms are still unmatched, and workers and firms believe that no applicant holds an open offer from a firm. Can firm j profit from deviating, by making an early exploding offer in period $t<7$ to applicant i who has probabilities $p_x(i)$ to be of quality x? This is profitable for firm j only if $\sum_{x=1,..,6} j \cdot p_x(i) > j(j+1)$.

To verify that applicant i's best response is to reject such an offer (and hence assure that in equilibrium no firm finds it profitable to deviate and make an early offer), we need to find beliefs $q_x(i)$ for applicant i such that he prefers to reject the offer and wait, i.e. $\sum_x j \cdot q_x(i) < \sum_x x(x-1) \cdot q_x(i)$, subject to $\sum_{x=1,..,6} j \cdot q_x(i) > j(j+1)$ (that is the

[45] To be precise, the information sets starting at period t+1 are not singletons, so the continuation of the game is not a subgame. But consider an auxiliary game G(t), derived from the path of play in the original game in which there is a match at period t<7. The players in the auxiliary game G(t) are all those players who are not yet matched by period t. The game G(t) begins at period t, and for that period only, firms may only make open offers. From period t+1 onward, the rules of the auxiliary game are those of the original game (i.e. both open and exploding offers may be made). Then the continuation strategies of the remaining (not yet matched) players in the original game are precisely equal to the strategies of players in the auxiliary game holding the same open offers.

applicant believes that firm *j* has not made a mistake by making an early exploding offer) and $q \in P^{s_i}$, that is beliefs *q* are feasible given applicant *i*'s signal s_i.

We will show that such beliefs exist by showing at the same time that this perfect Bayesian equilibrium does not hinge on the applicants not knowing the true probabilities of being of various types, that is not observing the vector of signals *s*. Specifically, we show that, along the equilibrium path, when all firms $k \neq j$ play according to their strategies, there is no nontrivial probability distribution over applicants' qualities (i.e. such that $0<p_x(i)<1$ for some $1\leq x\leq 6$), such that it is profitable for both the firm and applicant to deviate, that is the firm to make an early offer and the applicant to accept it.

► For a risk neutral firm *j* it is profitable to make an early offer (that is accepted) to applicant *i* of probabilities $p_x = p_x(i)$ to be of quality *x* whenever:

$$p_1 j + p_2 2j + p_3 3j + p_4 4j + p_5 5j + p_6 6j \geq j(j+1) \qquad \text{(F)}$$

The (risk neutral) applicant *i* with probabilities $p_x = p_x(i)$ to be of quality *x,* prefers to accept firm *j*'s offer whenever

$$p_1 0 + p_2 2\cdot 1 + p_3 3\cdot 2 + p_4 4\cdot 3 + p_5 5\cdot 4 + p_6 6\cdot 5 \leq p_1 j + p_2 2j + p_3 3j + p_4 4j + p_5 5j + p_6 6j. \qquad \text{(A)}$$

We now show, for each firm *j* that (F) and (A) can only be fulfilled if $p_{j+1}(i) = 1$, as long as no applicant is yet matched.

It is clear that when $\boldsymbol{j = 5}$, (F) cannot be fulfilled unless p_6=1.

For $\boldsymbol{j = 4}$:

Inequality (A) is $p_2 2\cdot 1 + p_3 3\cdot 2 + p_4 4\cdot 3 + p_5 5\cdot 4 + p_6 6\cdot 5 \leq p_1 4 + p_2 2\cdot 4 + p_3 3\cdot 4 + p_4 4\cdot 4 + p_5 5\cdot 4 + p_6 6\cdot 4.$

$$\Leftrightarrow \quad 4p_1 \geq -6p_2 - 6p_3 - 4p_4 + 4p_6.$$

Inequality (F) is $4p_1 + 8p_2 + 12p_3 + 16p_4 + 20p_5 + 24p_6 \geq 20$

We use that $\sum_i p_i = 1$ and obtain $\quad 4p_1 \leq -3p_2 - 2p_3 - p_4 + p_6$.

Combining (A) and (F) implies: $-3p_2 - 4p_3 - 3p_4 + 5p_6 \leq 0$

Which implies that $-15p_2 - 10p_3 - 5p_4 + 5p_6 < 0$ if $p_i > 0$ for at least one *i* of {2,3,4}.

The last strict inequality, with (F) delivers that $20p_1 < 0$: contradiction.

If $p_i = 0$ for i=2,3,4, then the combination of (A) and (F) imply that $p_6 = 0$, which using (F) implies that $p_1 = 0$ that means $p_5 = 1$.

For $\boldsymbol{j = 3}$:

Inequality (A) is $p_2 2\cdot 1 + p_3 3\cdot 2 + p_4 4\cdot 3 + p_5 5\cdot 4 + p_6 6\cdot 5 \leq 3p_1 + 6p_2 + 9p_3 + 12p_4 + 15p_5 + 18p_6.$

$\Leftrightarrow \quad 3p_1 \geq -4p_2 - 3p_3 + 5p_5 + 12p_6.$

Inequality (F) is $3p_1 + 6p_2 + 9p_3 + 12p_4 + 15p_5 + 18p_6 \geq 12$

We use that $\sum_i p_i = 1$ and obtain $3p_1 \leq -2p_2 - p_3 + p_5 + 2p_6$.

Combining (A) and (F) implies: $-p_2 - p_3 + 2p_5 + 5p_6 \leq 0$

Which implies that $-2p_2 - p_3 + p_5 + 2p_6 < 0$ if $p_i > 0$ for at least one *i* of {2,5,6}. The last strict inequality, with (F) delivers that $3p_1 < 0$: contradiction.

If $p_i = 0$ for i=2,5,6, then (F) implies that $p_3 = 0 = p_1$, which means $p_4 = 1$.

For $\boldsymbol{j = 2}$:

Inequality (A) is $p_2 2\cdot 1 + p_3 3\cdot 2 + p_4 4\cdot 3 + p_5 5\cdot 4 + p_6 6\cdot 5 \leq 2p_1 + 4p_2 + 6p_3 + 8p_4 + 10p_5 + 12p_6.$

$\Leftrightarrow \quad 2p_1 \geq -2p_2 + 4p_4 + 10p_5 + 18p_6.$

Inequality (F) is $2p_1 + 4p_2 + 6p_3 + 8p_4 + 10p_5 + 12p_6 \geq 6$

We use that $\sum_i p_i = 1$ and obtain $2p_1 \leq -p_2 + p_4 + 2p_5 + 3p_6$.

Combining (A) and (F) implies: $-p_2 + 3p_4 + 8p_5 + 15p_6 \leq 0$

Which implies that $-p_2 + p_4 + 2p_5 + 3p_6 < 0$ if $p_i > 0$ for at least one *i* of {4,5,6}. The last strict inequality, with (F) delivers that $2p_1 < 0$: contradiction.

If $p_i = 0$ for i=4,5,6, then (F) implies that $p_2 = 0 = p_1$, which means $p_3 = 1$.

For $\boldsymbol{j = 1}$:

Inequality (A) is $p_2 2\cdot 1 + p_3 3\cdot 2 + p_4 4\cdot 3 + p_5 5\cdot 4 + p_6 6\cdot 5 \leq p_1 + 2p_2 + 3p_3 + 4p_4 + 5p_5 + 6p_6.$

$\Leftrightarrow \quad p_1 \geq 3p_3 + 8p_4 + 15p_5 + 24p_6.$

Inequality (F) is $p_1 + 2p_2 + 3p_3 + 4p_4 + 5p_5 + 6p_6 \geq 2$

We use that $\sum_i p_i = 1$ and obtain $p_1 \le p_3 + 2p_4 + 3p_5 + 4p_6$.

Combining (A) and (F) implies: $2p_3 + 6p_4 + 12p_5 + 20p_6 \le 0$

Which implies that $p_i = 0$ for i=3,4,5,6, then (F) implies that $p_1 = 0$, which means $p_2 = 1$. ◄

Proof of Proposition 2 (late equilibrium in the Open offer only condition):

The strategies and beliefs are as follows:

In period 7, 8 and 9, firm *j,* the k-highest unmatched firm makes an offer to the k-highest unmatched applicant. Firms believe that no other firm makes or made an open offer to that applicant.

In periods t<9 applicants hold the best offer they receive and in period 9 accept the best available offer. (Applicants can accept the offer of the highest remaining firm as soon as they receive it, specifically, they can accept the offer of firm 5, the highest quality firm, in period t<9.)

Since offers are private, holding the best offer is always (weakly) better than accepting or rejecting it.

No firm has an incentive to make an early offer, as an applicant will simply hold any early offer, and accept it only if she didn't receive a better offer. This means, the firm will be matched with the applicant only if the applicant is of the quality the firm would make an offer to in period 7 anyway, or, of worse quality, in which case the firm is strictly worse off.

Firm *j,* the j-highest remaining firm in period 7, cannot gain by making an offer in period 7 to an applicant who is of a quality higher than the j+1 remaining applicant, as the applicant will receive a better offer in period 7. ◊

Proof of Proposition 3 (late equilibrium in the Renege condition):

We introduce a bit more notation for the equilibrium strategies of proposition 3, to define to which applicant each unmatched firm should make an offer at every information set in period 9. Each unmatched firm should make an offer to the correspondingly ranked unmatched applicant, or the highest ranked matched worker who would renege on his

previous acceptance and accept the firm's offer (given the other offers made simultaneously).

Let $of : F \setminus F^M \to C = \{1,2,...,6\}$ be the offer function defined by the following algorithm:

If firm $5 \in F \setminus F^M$ let $of(5) = 6 = \max\{c : c \in C = \{1,2,3,4,5,6\}\}$ and let $C^4 = C \setminus \{6\}$, if $5 \in F^M$ let $C^4 = C \setminus \{m(5)\}$.

In general, given C^k, for the firm of quality k the algorithm is: If firm $k \in F \setminus F^M$ let $of(k) = \max\{c : c \in C^k\}$ and let $C^{k-1} = C^k \setminus \{of(k)\}$, if $k \in F^M$ let $C^{k-1} = C^k \setminus \{m(k)\}$.

The algorithm stops at firm 1, and each firm in $f \in F \setminus F^M$ is assigned an applicant who is either unmatched or matched to a lower quality firm.

Let g^{F^M} be the generalized inverse offer function extended to matched as well as unmatched firms, that is $g^{F^M} : C = \{1,2,...,6\} \to F \cup \{0\}$ such that, given F^M, $g^{F^M}(c) = of^{-1}(c)$ for $c \in of(F \setminus F^M)$, $g^{F^M}(c) = f$ if $m(f) = c$, $c \notin of(F \setminus F^M)$ and $f \in F^M$, and $g^{F^M}(c) = 0$ for $c \notin \left(of(F \setminus F^M) \cup m(F^M)\right)$.

The beliefs and strategies that constitute this equilibrium are as follows:

Firms and applicants believe that all unobserved offers are exploding offers, that is, they believe that no applicant holds an offer, and that all unmatched firm are able to make an offer.

In period 9, the unmatched firm j among all the unmatched firms $F \setminus F^M$ makes an exploding offer to the applicant of quality $of(j)$ as prescribed by the offer function *of*.

In periods $t<9$ firms do not make offers.

The applicant holds the highest of all open offers he receives, and, in case he did not accept an exploding offer before, accepts the highest available offer in period 9.

In period 7 and 8, the applicant of quality c accepts any exploding offer from a firm whose quality is equal or higher than $g^M(c)$ (whether he is already matched or not), in case of receiving multiple offers he accepts the highest one.

In periods $t<7$, suppose the applicant has received signals s_i so far and receives an exploding offer from firm j. The applicant believes that he is the only applicant to receive an offer, and that rejecting the offer has no impact on other applicants' behavior, as rejected offers are private information. Given the set of matched firms F^M, the applicant forms beliefs $q^{s_i} \in P^{s_i}$, so as to maximize the difference in expected payoff from accepting the offer and rejecting the offer, that is q^{s_i} maximizes, subject to $p \in P^{s_i}$,

$$Q = \left[\sum_{\sigma} p(\sigma)\sigma(i)\max(j, g^{F^M \cup \{j\}}(\sigma(i)) - 1/\sigma(i))\right] - \left[\sum_{\sigma} p(\sigma)\sigma(i) g^{F^M}(\sigma(i))\right].$$ The applicant accepts the offer if $Q \geq 0$ and rejects it otherwise.

Given F^M, s and hence p we show that firm j has no incentive to make an exploding (or open) offer to applicant i, which the applicant would accept. (The firm knows whether the applicant would accept, and there are no incentives to make offers that are rejected.) If firm j makes an early offer that is accepted, the expected payoff is $\sum_{\sigma} p(\sigma)\sigma(i)\, jI$ where $I = 1$ if $j = \max\{j, g^{F^M \cup \{j\}}(\sigma(i))\}$ and 0 otherwise and where $g^{F^M \cup \{j\}}$ depends on σ.

If firm j does not make an early exploding or open offer (and no other firm does), then the expected payoff is $\sum_{\sigma} p(\sigma) j \cdot of(j)$, where of is the offer function, which depends on σ.

There are 3 possible outcomes:

1. $\sigma(i) = of(j)$. Then firm j is simply indifferent between hiring early or late.

2. $\sigma(i) < of(j)$. Then $j = \max\{j, g^{F^M \cup \{j\}}(\sigma(i))\}$ and firm j remains matched to $\sigma(i)$ and is strictly worse off from making an early offer.

3. $\sigma(i) > of(j)$. Then there exists a firm k such that $\sigma(i) = of(k)$, firm k will make an offer to applicant i in period 9, the applicant will renege and firm j will be unmatched, so, firm j is strictly worse off from making an early offer.

Therefore, firm j has no incentive to make an early offer.

Furthermore, in periods 7 or 8, firm j has no incentive to make an offer to an applicant of quality lower than $of(j)$, but also not to an applicant of quality higher than

$of(j)$, as then in period 9 the firm expects the applicant to renege on the acceptance and hence to be strictly worse off.

The strategies of the applicants are also a best response given their beliefs. ◊

Proof of Proposition 4:

We first show that in each information set of the exploding offer condition (that is given any set of matched firms and workers) and for any period $t<7$, the strategy that calls for the applicant to accept an exploding offer from j, is not a weakly dominated strategy.

Suppose applicant i receives an offer from firm j in period $t<7$. Suppose the applicant believes that all the other unmatched firms each made exploding offers to different applicants, which means that exactly one other applicant, say applicant k, is unmatched and has not received an offer. Suppose the applicant believes that all the other applicants accept their offer. For every set of signals applicant i has received so far, he can believe that there is a positive probability that applicant k, the unmatched applicant, will be of higher quality than i in period 7. In that case, applicant i is strictly better off accepting the early exploding offer from firm j.

Given that applicants may accept early offers, it is not a weakly dominated strategies for some firms (indeed, for every information set, for firm 1) to make an early exploding offer to the applicant who has so far received the highest signals.

Example of the exploding offer treatment.

To ease the presentation of the example, we introduce the following notation. Given a signal vector s, let p^6 be the expected quality of the applicant with the highest signal, and so on up to p^1. Let Best(p^j, p^k) be the expected quality of the applicant who has the higher final quality of (p^j, p^k). Similarly let Second(p^j, p^k, p^l) be the expected quality of the second highest applicant of the three applicants (p^j, p^k, p^l).

When $p^4 >$ Best(p^1, p^2) or $p^6 >$ max[Best(p^1, p^2), Second(p^1, p^2, p^3),4]; then all firms may have reasons to make early offers, and hence all applicants may have reasons to accept early offers, that is iterated elimination of weakly dominated strategies does not rule out early offers and acceptances. We show for each firm the case in which that firm is better off making an early offer, given that applicants accept early offers:

Firm 5: If firm 4 makes an early offer to the applicant p^6, firm 3 makes an offer to the applicant p^5, firm 2 makes an offer to the applicant p^4 and firm 1 makes an offer to the applicant p^3. Then if $p^6 >$ Best(p^1, p^2), firm 5 is better off making an early offer to the applicant p^6.

Firm 4: If firm 3 makes an offer to the applicant p^6, firm 2 makes an offer to the applicant p^5 and firm 1 makes an offer to the applicant p^4. Then if $p^6 >$ Second(p^1, p^2, p^3), firm 4 is better off making an early offer to the applicant p^6 than waiting and receiving the second best applicant of the remaining 3 applicants (since firm 5 will receive the best applicant of those).

Firm 3: If $p^4 >$ Best(p^1, p^2). Then if firm 5 makes an early offer to the applicant p^6, firm 4 makes an offer to the applicant p^5, firm 2 makes an offer to the applicant p^4 and firm 1 makes an offer to the applicant p^3. Then if $p^4 >$ Best(p^1, p^2), firm 3 is better off making an early offer to the applicant p^4.

If $p^6 > 4$, then if no firm makes an early offer, firm 3 is better off making an early offer to the applicant p^6.

Firms 2,1: It is always the case that $p^6 > 3$ – as in the extreme case of no signal, or all applicants receiving the same signal – the expected quality the applicant p^6 (as well as of p^1) is 3.5. Therefore, if no firm makes an early offer, firm 2 is better off making an offer to the applicant p^6. The argument is the same for firm 1.

Proof of Proposition 5 (iterated elimination of dominated strategies implies late matching in the open offer condition):

In period $t<7$, each applicant will only accept an offer from the highest remaining unmatched firm. The strategy of the applicant to accept another offer in period $t<7$ is always weakly dominated by holding that offer, as he may receive other offers, and receiving an offer from a firm is independent of the decision whether to accept, reject or hold the offer. Furthermore, since offers are private, holding the offer also dominates rejecting the offer. In period 9, the applicant will accept his highest offer.

Given these strategies of applicants, we show that no firm has an incentive to make an early offer in period $t<7$.

It is a weakly dominated strategy for firm 5 to make an offer to an applicant before it is clear that that applicant is of quality 6. (Firm 5 can only risk receiving a worse applicant). If firm 5 waits until period 7 (or 8 or 9) when the applicant of quality 6 is revealed and makes an offer to him, the applicant will still be available, because applicants' strategies that accept offers in period $t<7$, before firm 5 is matched were eliminated as weakly dominated.

Suppose firm 4 makes an offer in period $t<7$, to applicant i who has probabilities $p_y(i)$ to be of quality y in period 7.

The alternative strategy is for firm 4 to wait until period 7 and make an offer to the applicant of quality 5. Applicant 5 will still be available, as he will not receive an offer from firm 5, and does not accept other offers before period 7 (see above.)

If, in period 7, applicant i (whom firm 4 made an offer to in period $t<7$) has quality $6 > 5$, then firm 5 will make applicant i an offer. Applicant i will reject firm 4's offer, firm 4 did not benefit from making an early offer. In fact, firm 4 may be rejected in period 9 without having a chance to make another offer: in that case Firm 4 will be strictly worse off compared to making an offer in period 7, 8 or 9 to applicant of quality 5.

If, in period 7, applicant i has quality 5, then firm 4 did not benefit from making an early offer.

If, in period 7, applicant i has quality $y < 5$, then firm 5 (the only firm of quality higher than 4) will not make an offer to applicant i. Applicant i will accept firm 4's offer, firm 4 is strictly worse off by making an early offer.

Therefore, firm 4 will make an offer only in period 7, 8, or 9, to the applicant of quality 5 or higher (or to the applicant of the highest remaining quality if firm 5 matches early).

Now, we show it is a weakly dominated strategy (in the strategy set remaining after firm 5's dominated strategies have been eliminated) for firm 4 to make an offer in period 7-9 to applicant 6 (when firm 5 is still unmatched.)

We have seen that firm 5 will make an offer to applicant 6 in periods 7-9, so firm 4 cannot possibly match to applicant 6 (since applicant 6 accepts the best offer in period 9 only).

However, firm 4 can lose, as firm 5 may make the offer only in period 9, and so, firm 4 will get rejected by applicant 6 only in period 9, which leaves firm 4 unmatched, and hence strictly worse off compared to making an offer to applicant 5 in period 7-9.

Similarly we can show that this implies that (in the strategy set remaining after firm 5's and 4's dominant strategies have been iteratively removed) it is a weakly dominant strategy for firm 3 to make an offer only in period 7, 8 or 9 to the applicant of quality 4 (or the corresponding applicant if firms 4 and or 5 are already matched).

This in turn implies that firm 2 will not hire early, which implies that firm 1 will not make an offer early.

Proof of Proposition 6 (iterated elimination of dominated strategies implies late matching in the renege treatment):

In period $t<7$, each applicant will accept an offer from the highest quality firm that is still unmatched. In period 7-9, if the applicant is not matched yet, he will accept his highest offer. If the applicant is already matched, and receives a higher offer, he will renege on his former acceptance and accept the highest new offer he receives (recall that since matched agents receive the product of the qualities, the cost of reneging never exceeds the benefit of a better match).

Given these strategies of applicants, we show that no firm has an incentive to make an early offer.

It is a weakly dominated strategy for firm 5 to make an offer to an applicant before it is clear that that applicant is of quality 6. (Firm 5 can only risk receiving a worse applicant). If firm 5 waits until period 7, 8 or 9 when the applicant of quality 6 is revealed and makes an offer to him, the applicant will still be available, because he will renege on any former acceptance. Once firm 5's dominated strategies are eliminated, in the remaining strategy set it becomes weakly dominated for firm 4 to make an offer in period $t<7$, or to make an offer in period 7, 8 or 9 to any applicant that is not of quality 5. The proof, for firm 4, and then for firms 3,2, and 1, now proceeds as in the proof of Proposition 5.

Appendix: Instructions for the exploding offer treatment, the other instructions are adapted accordingly.

WELCOME

Thank you for participating in this experiment about economic decision making. It is important that during the experiment you remain silent. If you have any questions, or need assistance of any kind, please raise your hand, and I will come to assist you. Thank you for your cooperation.

The decisions made in this experiment are hiring decisions. Accordingly, your role will be either "firm" or "applicant." Your role, firm or applicant, will stay the same throughout the experiment. In other words, if you begin as a FIRM, you will remain a FIRM until the end of the experiment. Similarly, if you begin as an APPLICANT, you will remain an APPLICANT until the end of the experiment.

The experiment will have many "markets," which will last nine "periods" each.

If you are a "firm," to get a positive payoff in a given market of the experiment you will need to hire one, and only one, applicant in that market.

If you are an "applicant" you will need to accept one, and only one, job offer in each market of the experiment.

In each group, there are five firms and six applicants. The firms are numbered 1 through 5, and the applicants are numbered 1-6.

The firms and applicants are assigned "qualities." Your payoff as a firm is your quality multiplied by the quality of the applicant you have hired. Similarly, your payoff as an applicant is the product of your quality and your employing firm's quality. For example, if a firm of quality 3 hires an applicant of quality 4, both firm and applicant will receive a payoff of 3x4 = 12 points each.

Firms' qualities are simply their assigned participant number. In other words, if you are firm 3, your quality is 3. If you are firm 4, your quality is 4.

Applicants' "qualities," in contrast, have nothing to do with their assigned ID number and depend solely on the applicant's "grades" and "scores."

Exactly how are applicants' qualities determined?

In period 1, 4 and 7, each applicant receives a "grade," which is a number between 1 and 10, with 10 being the best possible grade and 1 being the worst possible grade. The computer generates these grades randomly, with each of 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10 having an equal chance of occurrence.

So, in period 1, each applicant has a grade between 1 and 10, which is the applicant's "1. score." In period 4 the applicant receives a second grade from 1 to 10. The sum of the

first grade (from period 1) and the second grade (from period 4) is the applicant's "2.score." In period 7 each applicant receives a third grade between 1 and 10. The sum of the first, second and third grade is the applicant's "3. score."

The "3. score" determines the applicant's final quality, through its ranking relative to the other applicants' "3. scores". The applicant with the highest "3. score" has a quality of 6. The applicant with the second highest "3. score" has a quality of 5, and so on. The applicant with the lowest "3. score", has a quality of 1. In case of ties, that is, when two applicants have the same "3. score," the computer will break ties and randomly give one a higher quality than the other.

For example, let's say that applicant 5 receives in period 1 a grade of 2, so the "1. score" is 2. In period 4 applicant 5 receives 6, so the "2. score" is 2+6=8. In period 7 the applicant receives a grade of 9 which means the "3. score" is 2+6+9=17. Let's say that the other 5 applicants have "3. scores" of 22, 15, 15, 12 and 7. Then, our applicant 5 has the second highest "3. score" and is assigned quality 5. The two applicants with "3. score" 15 get qualities 4 and 3 (they are the third and fourth highest). The computer will randomly determine which of the two receives quality 4 and which quality 3.

In the experiment you will see only the scores (not the grades from which they are composed), but now you know how they are determined. The "1. score" will be available at the beginning of period 1, the "2. score" will become known in period 4, and the final "quality" of each applicant will be known starting in period 7.

Making and accepting offers

Firms can make two types of offers:
An *exploding* offer is an offer that the applicant can only accept or reject right away, in the same period as the offer was made.
An *open* offer is an offer that the applicant can accept, reject or "hold". An open offer can be held by the applicant until the last period, when he has to decide whether to accept or reject the offer. An open offer will remain open as long as the applicant holds it. (Each applicant who hasn't already accepted an offer can hold no more than one offer at a time.) A firm with an open offer that is being held cannot make another offer: a firm can only have one offer outstanding at any time.

Firm's decisions in each period

A firm that has not yet hired an applicant, and has no open offer being held by an applicant, has to decide whether to make an offer, and, if so, to which applicant. A firm may make at most one offer in a period. Once the firm types in the ID number of the applicant to whom the offer is made, the firm has to decide whether to make an open or exploding offer. An exploding offer is one the applicant has to accept or reject in this period. If the offer is open, the applicant can also choose to hold the offer, and postpone the decision whether to accept or reject it. A firm can only have one offer outstanding in each period, so a firm with an open offer that is held by an applicant cannot make another offer.

Applicants' decisions in each period.

In each period the applicant sees all the offers she has received that period, including possibly an open offer she decided to hold from the previous period. The applicant has to decide whether to accept or reject her offers. If the offer is an open offer, the applicant can decide to hold this offer, which means this offer will be available for her also next period. (An open offer that was held from the previous period must be held again at this period if the applicant wants to continue to hold it.) In any period the applicant can only hold one offer. All the offers that are not accepted or held are automatically rejected. (In the last period, period 9, the applicant can only accept or reject offers). When an applicant accepts an offer from a firm, we say the applicant and the firm are matched to each other.

Once a firm and an applicant are matched, the firm cannot make any further offers, and the applicant cannot accept any further offers. The firms cannot make offers to applicants who are matched, so a matched applicant will not receive any further offers.

The information on the Screen of Applicants and Firms:
In the top left box you can see whether you are a firm or an applicant. Let's start by looking at a sample screen for one of the firms: we are looking at a screen of Firm 2.

The screen shot is from period 7, at which point all the information about applicants, their "1. score", their "2. score" and their final "quality" is available. (In periods 1-3 only the "1. score" is available, in periods 4-6 the "1. score" and the "2. score" are available, and the final quality is only available starting at period 7.)

If you are a firm, your ID number (and hence your quality) will remain fixed across markets.

In the top right you can see the current period in the market. Each market has 9 periods, and new information about the applicants becomes available in periods 1, 4 and 7. Any firm (and applicant) who is not matched by the end of period 9, remains unmatched in this market, and earns zero points.

On the bottom right there is a box called "Applicant's Scores". In this box is a list of applicants' scores and qualities as they become available over time. The ordering is according to the applicants' ID numbers (which are randomly assigned in every market). In the sample screen you can see that Applicant 1 has quality 5, while applicant 3 has quality 2.

On the top left the firm has a box called "Matchings" which shows which of the firms have already hired which applicant, at what period and with what score or quality. The entries are ordered by year of acceptance of the offer by the applicant. For firm 2, the entry that corresponds to firm 2, is marked by ** 2 ** instead of just 2 in the column labeled "hired by firm".

On the bottom right the firm has a box that reminds them of the points they receive for a match.

All the boxes we discussed so far, are also available on the screen of the applicants. Now we discuss the part that is specific to firms.

The box headed "List of Applicants" shows for each applicant the relevant score or quality, and by which firm they are hired (where 0 means they are not hired by any firm yet). Note that on this list, applicants are listed in order of quality (or, before period 7, in order of their most recent score, with the highest scoring applicant listed at the top of the list, etc.). Thus on this screen, applicant 4 is listed first, with a quality of 6, applicant 1 is next, and so forth.

In the box below, the firm can choose to make an offer. To make an offer, the firm types in the ID of the applicant to whom the offer is directed, and then clicks on the choice of an "exploding" or "open" offer. To make the offer the firm has to click the "make offer" button. The firm cannot make an offer to an applicant who is already matched to another firm.

If the firm does not want to make an offer, or is already matched or has an open offer held by an applicant, the firm has to click the "No Offer" button.

On the left, in the middle, the firm can see if she is already matched (has already hired an applicant) and which one. The second line shows if the firm has an open offer and to which applicant. In period 7 the last line appears that shows the points the firm receives in this market, if she is already matched (it shows 0 points if she is unmatched). In our example, firm 2 and applicant 1 (of quality 5) are matched to each other, and hence firm 2 (and applicant 1) earn each 2x5 =10 points in Market 1.

Below, on the bottom left, is a table that shows each firm all her offers that were rejected in this market. For example, Firm 2 made an exploding offer in period 1 to applicant 1 that was rejected in period 1.

The Applicant:
The screen shot is from applicant 2 in period 7 (as can be seen in the top 2 boxes). Each applicant will receive a new ID number in every market, which has nothing to do with the final quality that is determined throughout the market.

The table headed "The scores" lists your scores and qualities as they become available over time. Applicant 2 turns out to have quality 4 in this example; this means he has the third highest quality (the highest is 6, the lowest is 1).

The applicant has a box called "Matchings," showing which of the firms have already hired which applicant, at what period. The entries are ordered by year of acceptance of the offer by the applicant.

Now we discuss boxes and choices that are only available to applicants.

On the right side the applicant has a table called "Your offers" that shows all the offers available (for this applicant) this period and whether the offer is exploding or open. (By

the time you see this screen, firms have finished making their offers for this period, so this screen shows all the offers you will receive in this period.) In the example, applicant 2 has one exploding offer, from firm 1. (Applicant 2 has to decide what to do with this offer, but he has no need to wait for further offers in this period, as all the firms have already finished making offers.) To accept an offer, the applicant has to first *click on the offer* and then the "Accept offer" button. Once an applicant accepted an offer, he is matched to that firm (i.e. hired by that firm) for this market, and will not receive any subsequent offers. The applicant can also decide to hold at most one open offer, by typing in the firm's ID number (and hence the firms' quality) that made him such an offer, and click the "Hold Offer" button. In that case the applicant will have this offer available in the next period. If an applicant holds an offer, all the other offers are automatically rejected. The applicant can also decide to reject all offers by clicking the Reject / Continue button. If the applicant received no offers, he nevertheless has to click the "Reject / Continue" button so the experiment can proceed. *Once you have made your decision, click the necessary button promptly, in order that the experiment will not take an excessively long time.*

The table in the middle left shows whether and to whom the applicant is matched, whether the applicant decided to hold an offer and from which firm. In period 7 the last line appears that shows the points the applicant receives in this market, if he is already matched (otherwise it shows 0 points).

The box in the bottom left shows the offers the applicant rejected in this market, ordered by the year in which they were rejected.

PAYMENT:
The payment you receive in this experiment has two components.
The first is based on your performance in the experiment: For each point you accumulate in the experiment, you receive $ 0.10. The second component is independent of your performance in the experiment, and already determined in advance. It consist of the $10 show up fee, and for some types of players (already determined) another fixed payment that is already determined now. That is, your behavior in the experiment influences your payoff only through the points you accumulate in the markets.

SUMMARY:
At the beginning of the experiment you learn whether you are a firm or an applicant. If you are a firm, you also learn your quality, which is your ID number that you will have throughout the whole experiment. If you are an applicant, you receive a new ID number in every market, and your ID number has nothing to do with your quality. In each Market there are 5 firms and 6 applicants.

Information about Applicants' qualities is revealed over several periods:

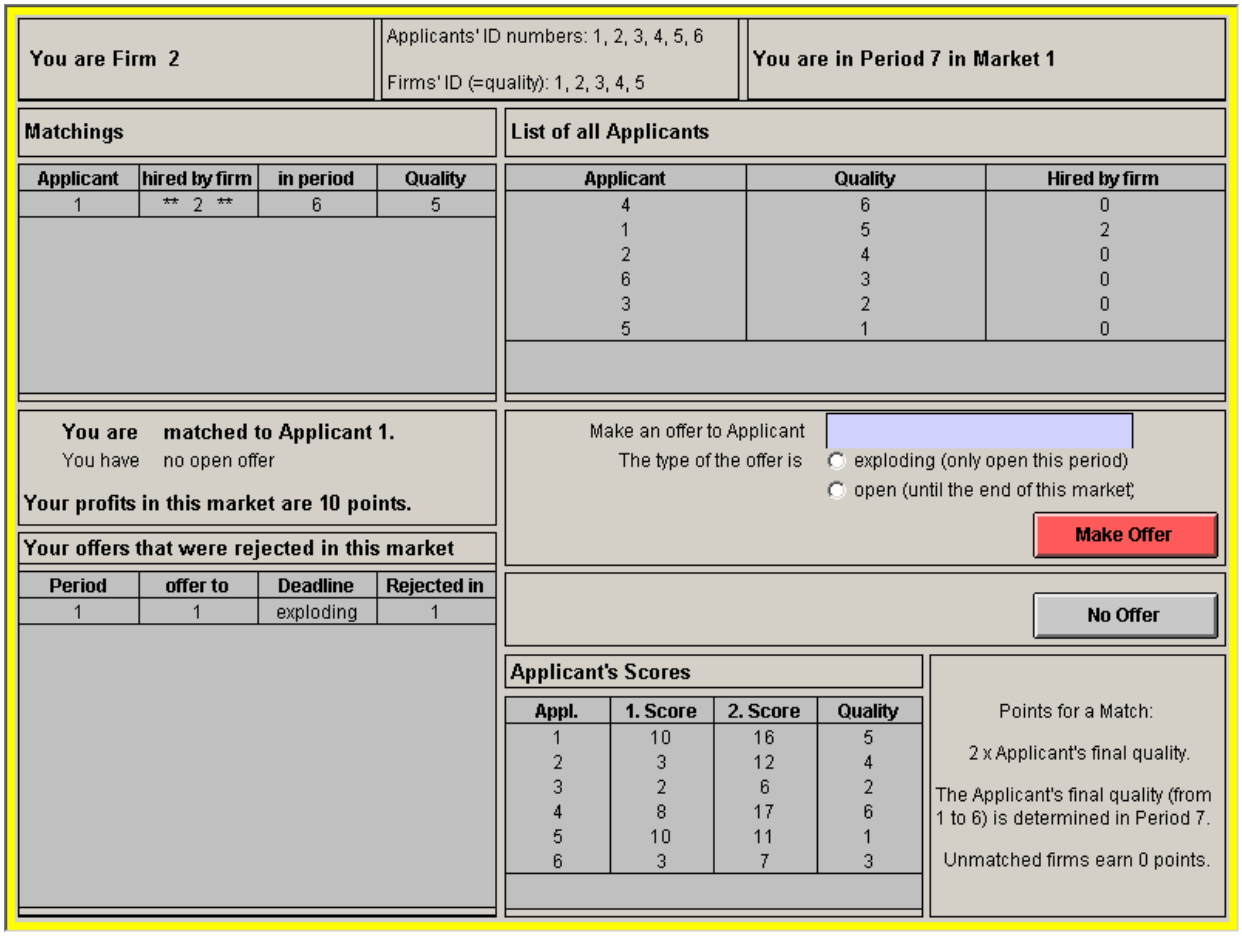
- Period 1: Each Applicant receives a grade between 1 and 10 (with each of 1,2,3,4,5,6,7,8,9,10 having an equal chance to occur) that is his "1. score".
- Period 4: each applicant receives another grade of 1,..,10, (each having the same chance of occurring) and the sum of the two grades constitute the "2. score".
- Period 7: Each applicant receives a third grade between 1,..,10 (each having the same chance of occurring), and the sum of all three grades constitute the "3.

score". The applicant with the highest 3.score receives the highest quality of 6, the applicant with the second highest receives quality 5, and so on, until the applicant with the lowest score who receives quality 1.

To earn points in a market, a firm will need to hire one, and only one, applicant in that market, and an "applicant" will need to accept one, and only one, job offer. How is this done?

- In each period, each firm that has not yet hired an applicant, and has no open offer being held by an applicant, has to decide whether to make an offer, and, if so, to which applicant, and whether the offer should be exploding or open. Each firm can only have one outstanding offer in each period.
- An exploding offer is an offer to which the applicant must respond immediately. If he does not accept it right away (i.e. in the same period that it was made), the offer expires, and it is as if he had rejected it.
- An open offer is an offer the applicant can accept, reject, or hold. At most one offer can be held, in which case it will remain available in the next period.
- Once all the firms have made their offers, the applicants see the screen showing all the offers they received this period. (Once an applicant sees his offer screen, there will not be any further offers arriving in that period.)
- In each period, applicants who receive offers have to decide whether to accept the offer, reject the offer, or, if the offer is an open offer, the applicant can decide to hold (no more than one) offer.
- Once an applicant accepted an offer, he cannot accept another offer in the same market, and will no longer receive offers.
- Firms and Applicants that are not matched by the end of period 9 in a market remain unmatched and earn zero points.
- Firms and applicants that are matched to each other each earn points equal to the product of the applicant's quality and the firm's quality.
- After period 9, a completely new market begins, and everyone is free to try to match once again.

Screen of Firm 2



Screen of Applicant 2