The Timing of Transactions: Congestion

Centralized market clearinghouses tend to arise in response to certain kinds of market failures, and today we're going to talk more about *congestion*. This will lead us to think about decentralized approaches to dealing with congestion as well, and we'll talk about *signaling*.

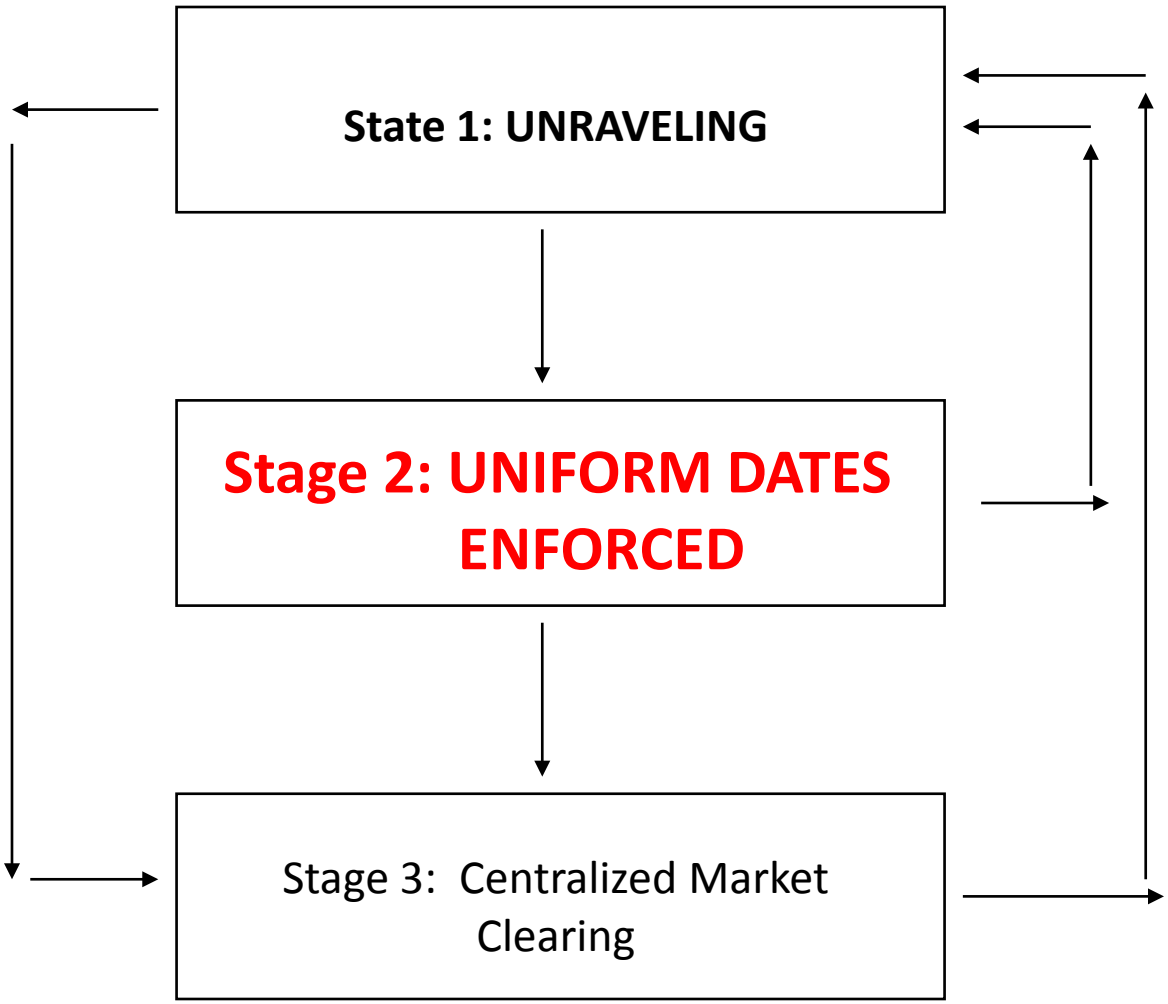
Economists have spent a lot of effort thinking about the price of transactions, but much less about their timing. . We already observed that one reaction to congestion is to try to make transactions *earlier*, and that this *unraveling* of transaction dates can cause problems of its own.

Today we'll start by observing that *transactions take time*, so markets can't clear instantly, they get congested

- the timing of transactions, and agents' strategic use of timing decisions, have an important influence on the evolution, organization, and performance of markets, i.e. in how the rules change over time, in what market institutions we see, and on what outcomes are produced.

I'll also focus on the use of different tools (theoretical, computational, experimental, historical).

Stages and Transitions



The Market for Clinical Psychology Interns

In 1998, this market converted to a centralized match using the Roth-Peranson algorithm (run for the first time in the academic year '98-99 for jobs beginning in June 1999.) For approximately 25 years prior to that, a decentralized market was run, under a changing set of rules.

Part of market design for an existing market involves understanding the problems the market is encountering. The decentralized psychology market was studied in

Roth, A.E. and X. Xing "Turnaround Time and Bottlenecks in Market Clearing: Decentralized Matching in the Market for Clinical Psychologists," *Journal of Political Economy*, 105, April 1997, 284-329.

In the early 1990's, transactions in this market were supposed to all be made by telephone on "Selection Day," the second Monday in February, from 9:00 AM to 4:00 PM Central Standard Time. That is, the market was supposed to operate for seven hours.

Subject to many modifications of its rules, this kind of decentralized but uniform timing regime was used in this market since 1973.

One kind of modification has concerned the length of the market. In the early 1970's the market lasted *five days*, and was subsequently shortened to *three*, and for most of the 1980's the rules specified that the market would take place from 8:00 AM Monday until Noon the following day, i.e. for a *day and a half*.

Once again, by the 1990's this time had been shortened to *seven hours*, and in the late 90's it was shortened further (I think to *four* hours).

(This concern with the amount of time which the market, and individual offers, should remain open is one that has been observed in many markets, and is one of the things this market will shed some light on.)

[NB: **Rules are data!** They evolve over time, and illuminate not only the basic transactions going on, but give a good idea of how people are gaming the system, since it is seldom necessary to add a rule against behavior no one is exhibiting…☺]

APPIC Policy: Internship Offers and Acceptances (5/91)
Adherence to these policies is a condition of membership in APPIC

"Selection day" currently begins at 9:00 am Central Standard Time on the second Monday in February, and ends at 4:00 pm that same day. This definition is subject to change.
…

3. No internship offers in any form may be extended by agencies before the beginning of selection day.

a. The ***only*** information that agencies may communicate to applicants prior to this time is whether or not the applicant remains under consideration for admission (see item 2). The spirit of this item precludes any communication of an applicant's status prior to the time above, however, "veiled" or indirect such communication might be.

b. …

c. Internship programs may not solicit information regarding an applicant's ranking of programs or his/her intention to accept or decline an offer of admission until after that offer is officially tendered. *<ha!>*

4. Applicants must reply to all offers no later than the closing time on selection day.

a. This deadline applies to all offers including those to applicants who are initially considered "alternates" and are subsequently extended an offer any time prior to end of selection day.

b. Agencies may inquire as to the applicant's progress towards making a decision at any time after an offer is formally extended. *Under no circumstances, however, may an agency implicitly or explicitly threaten to rescind an offer if a decision is not made prior to the end of selection day* (except as noted in item 6).

c. It is in everyone's best interest that applicants make and communicate decisions to accept or reject each offer *as quickly as possible*.

d. Any offer that has not been accepted is void as of the ending hour of selection day.

Rules 5+6: “Deferred acceptance by telephone”

5. **An applicant must respond immediately to each offer tendered in one of three ways. The offer may be accepted, rejected or "held."**
    a. *Accepting* the offer constitutes a binding agreement between applicant and internship program.
    b. *Refusing* the offer terminates all obligations on either side and frees the internship program to offer the position to another applicant.
    c. *Holding* the offer means that the offer remains valid until the applicant notifies the program of rejection or acceptance, or until the end of selection day.

6. **Applicants may "HOLD" no more than one active offer at a time.**
    a. If an applicant is holding an offer from one program and receives an offer from a more preferred program, s/he may accept or "hold" the second offer provided that the less preferred program is notified *immediately* that the applicant is rejecting the previously held offer.
    b. If a program confirms that an applicant is holding more than one offer, the program is free to withdraw their previously tendered offer of acceptance, and to offer that position to another applicant *after* the offending applicant is notified of that decision.

7. An offer of acceptance to an applicant is valid only if the applicant has not already accepted an offer of admission to another program.

a. An applicant's verbal acceptance of an offer constitutes a *binding agreement* between the applicant and the program that may not be reversed unilaterally by either party.
b. Before programs extend an offer, they must first *explicitly* inquire whether the applicant has already accepted an offer elsewhere. If so, no offer may be tendered.
c. *A program may in no way suggest* that an applicant renege on previously accepted offers.
d. *If an applicant who has accepted an offer receives a second offer*, s/he is obligated to refuse the second offer and inform the agency that s/he is already committed elsewhere.
e. Any offer accepted subsequently to a prior commitment is automatically null and void, even if the offering agency is unaware of the prior acceptance and commitment.

8. When an applicant accepts an offer of admission, s/he is urged to immediately inform all other internship programs at which s/he is still under consideration that s/he is no longer available.

Rule 9: "Aftermarket"

9. **Applicants who have not accepted a position prior to the end of selection day may receive offers of admission after that deadline.**
   a. Applicants should be prepared to accept or reject such late offers quickly, since most other deliberations should have already taken place.
   b. Programs may legitimately place short but reasonable (☺) deadlines for responses to such late offers.

10. **Once a program has filled all available positions, all candidates remaining in their applicant pool must be notified that they are no longer under consideration.**
    a. Applicants who have not notified the agency that they have accepted a position elsewhere and who have not been selected by the agency should be notified by phone as soon as all positions are filled.
    b. If an applicant cannot be reached by phone, s/he should be so notified by letter postmarked no later than 72 hours after the end of selection day.

11. **Internship training directors should document their verbal agreement with each applicant in a letter postmarked no later than 72 hours following the end of selection day.**
    a. The letter should be addressed to the applicant, and should include confirmation of conditions of the appointment, such as stipend, fringe benefits, and the date on which the internship begins.
    b. A copy of that letter should be sent simultaneously to the applicant's academic program director.

12. **Applicants who receive offers which do not comply with these policies or who in other ways detect violations of these policies by an APPIC member program are urged to request compliance with APPIC policies from the program representative.**
    a. Applicants should immediately report any problems unresolved after such request to his/her academic program director.
    b. Academic program directors are urged to contact internship training directors immediately regarding such unresolved problems.
    c. Such compliance problems should be resolved through consultation among applicant, internship program, and academic training director whenever possible.
    d. Problems not amenable to resolution through such consultation should be reported as soon as possible to the APPIC Standards and Review Committee …

13. Internship directors who become aware of violations of policies on the part of students, academic training directors, or other internship directors are urged to immediately request compliance to the policies.

a. Internship directors are urged to contact academic training program directors immediately regarding problems that remain unresolved after such a request for compliance.
b. Internship program directors who become aware of violations of these policies by other internship programs should urge the applicant and academic training directors involved to follow the procedures outlined in 12 a-d above, and/or directly contact the other internship director.
c. Such compliance problems should be resolved through consultation among applicant, internship programs, and academic training director whenever possible.
d. Failure to resolve compliance problems through consultation should be reported to the APPIC Standards and Review Committee.

14. All reported violations of these policies will be considered by the APPIC Standards and Review Committee (SRC). SRC policies are described in the *APPIC Directory*. Violations of these policies should be reported to: Chair, APPIC Standards and Review Committee

(*These don't look like the rules of a trouble-free market…)*

Behavioral Observations on Selection Day

Transaction times were *FAST*:

Offers took about 5 minutes to deliver
Rejection of offers took about 1 minute
New offers were made immediately following a rejection

Surveys of students report that > 10% got early offers

There was a great deal of pressure on students to indicate a 1st choice (despite very explicit rules prohibiting such pressure)

There was considerable willingness by students to indicate a 1st choice. (And repeated game issues seemed to make these signals credible… "you see these people again…")

Employers paid serious attention to indications of first choice, in deciding to whom to give offers.

(We'll come back to this when we talk about *signaling*…)

Question: why isn't this fast, decentralized process inducing the behavior we'd expect from the (centralized) deferred acceptance procedure?

"… it may help to recount the situation at an internship program we visited on selection day in 1993. This program had 5 positions, and received 200 inquiries which turned into 71 applications. Invitations were issued to 30 candidates for interviews, and 29 accepted. On selection day, the two program co-directors, who would make the calls, came equipped with a rank ordered list of 20 acceptable candidates from among those interviewed. …

"… the codirectors said their general strategy was 'don't tie up offers with people who will hold them all day.' They therefore decided to make their first offers… to numbers 1, 2, 3, 5, and 12 on their rank order list, with the rationale that numbers 3, 5, and 12 had indicated that they would accept immediately, and that 1 and 2 were … "worth taking chances on. Two phones were used to make these calls, starting precisely at 9:00 am... Candidates 3, 5, and 12 accepted immediately, as promised. Candidate 1 was reached at 9:05 (on the fourth attempt, after three busy signals) and held the offer, until 9:13 when he called back to reject it. During this period, an incoming call (on a third phone whose number had been given to candidates) was received from the candidate ranked 8th, who now said that the program was her first choice. She was thanked and told she was still under consideration, and when candidate 1 called to reject the offer he was holding, the codirectors decided to make the next offer to candidate 8 (and not to number 4, as initially planned). The offer to number 8 was then made and accepted immediately, and while that phone call was in progress, an incoming call from candidate 2 informed them that she had accepted another position. The decision was then made to offer the remaining position next to the highest ranked remaining candidate who had indicated he would accept immediately, number 10, and this offer was accepted at 9:21." (Roth and Xing, 1997)

Decentralized deferred acceptance with random elements (with and without an aftermarket)

initial state: t=0, all positions are vacant, all workers are unmatched, no communication is underway.

Preferences: **P** = $[P(F_1),...,P(F_n);P(w_1),...,P(w_m)]$ selected from some specified joint probability distribution.

1. Offers, deferred acceptances, and rejections:

a. All *available* firms, i.e. firms which are not currently engaged in communication and which have at least one position for which no offers are outstanding, attempt to make offers to their most preferred workers who haven't yet rejected them. Some subset of this set (containing no more than one firm seeking to make an offer to any given worker) succeeds in establishing communication with the worker to whom they wish to make an offer--this successful set is determined according to some specified probability distribution (which may depend on the current state of the system). Successful firms remain in communication with the workers they have contacted for some time period drawn from a specified distribution.

b. Any worker who receives an offer rejects it if it is unacceptable or if she has already received an offer from a more preferred firm. Otherwise she holds it (so that the firm in question has an offer outstanding for the position). [workers who have received an offer from the first choice among those remaining on their lists can now accept the offer, and inform all firms, and firms who have had all positions accepted can now inform all applicants that their positions are filled]

2 a. Is there any firm which has not already been rejected by all of its acceptable workers and which has a position not presently being held by any worker?

No

STOP. In this case the final outcome is the matching ì which matches each worker to the position (if any) that she is holding.

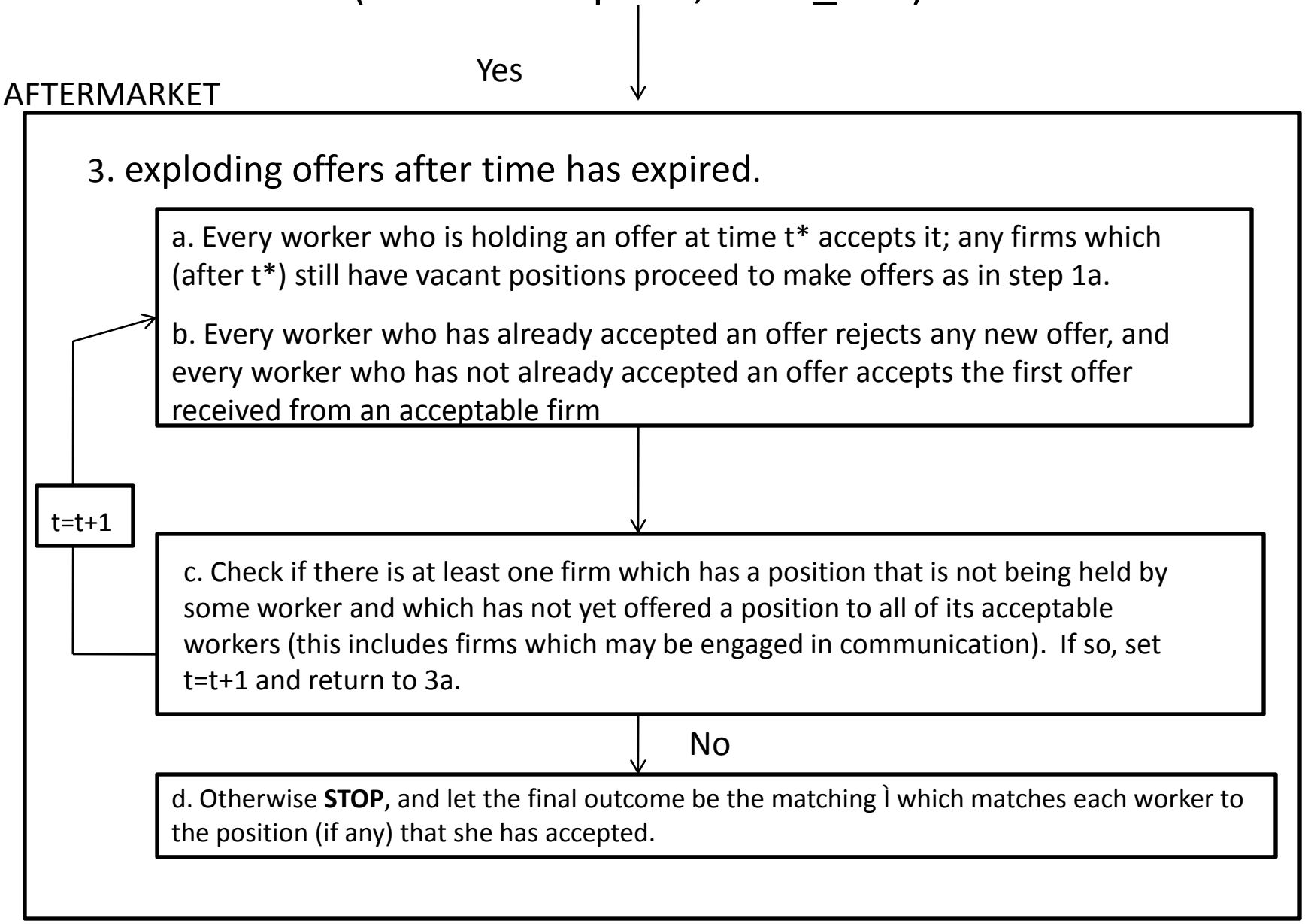
Yes

b. Set t = t+1. Has time expired, i.e. $t \geq t^*$?

(No after-market)

No

Yes


(Has time expired, i.e. t ≥ t*?)
Yes
AFTERMARKET
3. exploding offers after time has expired.
a. Every worker who is holding an offer at time t* accepts it; any firms which (after t*) still have vacant positions proceed to make offers as in step 1a.
b. Every worker who has already accepted an offer rejects any new offer, and every worker who has not already accepted an offer accepts the first offer received from an acceptable firm
t=t+1
c. Check if there is at least one firm which has a position that is not being held by some worker and which has not yet offered a position to all of its acceptable workers (this includes firms which may be engaged in communication). If so, set t=t+1 and return to 3a.
No
d. Otherwise **STOP**, and let the final outcome be the matching Ì which matches each worker to the position (if any) that she has accepted.

Theorem 1: If the decentralized deferred acceptance procedure is run *without any fixed termination time (i.e. $t^* = \infty$),* then the outcome would be the same stable matching as that produced by the centralized deferred acceptance procedure. In particular, both procedures produce the firm-optimal stable matching with respect to the revealed preferences, μ_F.

Proof: familiar…

When the decentralized deferred acceptance algorithm is run with finite termination time, it's output is a *random matching*. So we might worry that the results will depend on the particular utility functions of the participants, and not just their ordinal preferences. But in fact we get theorems that involve stochastic dominance, so the results apply to all expected utility functions.

Given two random matchings $\underline{\underline{\mu}}^1$ and $\underline{\underline{\mu}}^2$ and a worker w with preferences P_w over $\mathbf{F} \cup w$, we say that $\underline{\underline{\mu}}^2(w)$ *stochastically P_w-dominates* $\underline{\underline{\mu}}^1(w)$, (and write $\underline{\underline{\mu}}^2 \succ_w \underline{\underline{\mu}}^1$) if for every v in $\mathbf{F} \cup \{w\}$,

$$\Pr\{\underline{\underline{\mu}}^2(w) >_w v\} \geq \Pr\{\underline{\underline{\mu}}^1(w) >_w v\},$$

i.e. for any level of satisfaction the probability that w's match exceeds that level of satisfaction is greater under the random matching $\underline{\underline{\mu}}^2$ than under $\underline{\underline{\mu}}^1$. So if $\underline{\underline{\mu}}^2 \succ_w \underline{\underline{\mu}}^1$ then any utility maximizer with ordinal preferences P_w prefers $\underline{\underline{\mu}}^2(w)$ to $\underline{\underline{\mu}}^1(w)$.

Theorem 2: For markets in which there is *not* an aftermarket, let $\tau < \tau' < \infty$, and let $\underline{\mu}^{\tau}$, $\underline{\mu}^{\tau'}$, and $\underline{\mu}^{\infty}$ be the random matchings which result from otherwise identical decentralized deferred acceptance procedures with random elements, having termination times τ, τ', and ∞, respectively. Then for any student w with realized preferences P_w,

$$\underline{\mu}^{\infty}(w) \succ_w \underline{\mu}^{\tau'}(w) \succ_w \underline{\mu}^{\tau}(w).$$

Proof: by observation that a student's welfare (weakly) rises throughout on any realization of the firm-proposing random algorithm.

Counterexample: For a market *with* an aftermarket, it is not the case that if $\tau < \tau'$ then $\underline{\mu}^{\tau'}(w) \succ_w \underline{\mu}^{\tau}(w)$.

Proof: Suppose $\mathbf{F} = \{F_1, F_2\}$, $W = \{w_1, w_2\}$ and the two firms always have the preference $w_1 >_F w_2$ for F in **F**, and each worker always has the same preference as the other; either $F_1 >_w F_2$ for each w in W, or the reverse.

The firm optimal stable matching matches w_1 to the most preferred firm; this is the outcome in the deferred acceptance process with $t^* = \infty$. Consider $t^* = \tau < \infty$ with τ small enough so there is time for only one offer to reach w_1, so there is a positive probability that w_1 will have received only an offer from the less preferred firm at time τ, i.e. a positive probability that $\underline{\mu}^{\tau}(w_1)$ is the less preferred firm while $\underline{\mu}^{\tau}(w_2)$ is the more preferred firm (with the match made in the aftermarket). Then the firm optimal stable matching doesn't stochastically dominate $\underline{\mu}^{\tau}(w_2)$…

Theorem 3: *Conditional* on *having received* at least one acceptable offer *by* time τ, the distribution of $\underline{\underline{\mu}}^{\tau'}(w)$ stochastically dominates that of $\underline{\underline{\mu}}^{\tau}(w)$ and is stochastically dominated by $\underline{\underline{\mu}}^{\infty}(w)$ for $\tau < \tau' < \infty$. That is, for every v in $F \cup \{w\}$,

$\Pr\{\underline{\underline{\mu}}^{\tau'}(w) >_w v \mid w(\tau) \neq 0\} \geq \Pr\{\underline{\underline{\mu}}^{\tau}(w) >_w v \mid w(\tau) \neq 0\}$

Theorem 4: Let $\tau < \sigma < \infty$, and let $\underline{\underline{\mu}}^{\tau}$, $\underline{\underline{\mu}}^{\sigma}$, and $\underline{\underline{\mu}}^{\infty}$ be the corresponding random matchings resulting from straightforward play. Then *conditional* on all its positions *being held at time* τ, the distribution of $\underline{\underline{\mu}}^{\tau}(F)$ stochastically dominates that of $\underline{\underline{\mu}}^{\sigma}(F)$, which stochastically dominates that of $\underline{\underline{\mu}}^{\infty}(F)$, from the point of view of a firm F with preferences P(F).

Notice that Theorem 4 is much more delicate than theorem 3: the welfare of firms is hard to predict, since a firm can be rejected right near the end of the market.

The need for computation: is 7 hours near or far from . $t^* = \infty$, given how fast offers and replies are?

Basic Simulations (Variations to follow…)

"Medical model": deferred acceptance until natural termination (no time limit)

- 200 workers, each with uniform random preferences over 20 randomly selected firms
- 50 firms, each with 4 positions, and uniform random preferences over all workers who apply.

Each firm has two phones for outgoing calls, one for incoming

Actions take place each minute.

- Offers take 5 minutes
- Rejections take 1 minute
- Information calls (following acceptances, or all positions filled) take 1 minute.

Table 1: The Medical Model Telephone Market
Results of 100 simulations for each three turnaround times

Number of minutes required			
to make an offer	**5**	10	25
to reject an offer	**1**	2	5
Mean time to termination at a stable outcome (standard deviation)	**18:18** (8:10)	**36:32** (16:20)	**91:14** (40:52)
Mean time by which 90% of students have received an offer	**1:02**	2:03	5:04
Mean time by which 99% of students have received an offer	**5:19**	10:35	26:22
Longest time to termination	**39:25**	78:25	196:22
Shortest time to termination	**4:59**	9:55	25:00

A lot happens in the first hour, then things slow down. And busy signals aren't playing a role: when transaction times are increased, everything scales up proportionally.

Table 2: Hourly Progress of the Medical Model Telephone Market

Mean results based on 100 simulations.

Hour	# Students Who Have Received at Least One Offer	# Students Who Have Received an Offer From the Firm to Which They Will Ultimately Be Matched	# of Offers That Have Been Made	# of Offers That Have Not Been Rejected Immediately
0	0.00	0.00	0.00	0.00
1	**178.47**	**86.32**	**400.08**	**278.06**
2	**191.24**	**116.06**	**531.96**	**333.90**
3	**194.83**	**132.75**	**602.36**	**360.04**
4	196.50	143.81	648.58	375.70
5	197.41	152.14	681.79	386.80
6	198.02	158.48	707.38	395.01
7	**198.37**	**163.37**	**727.89**	**401.10**
8	198.54	167.66	745.23	406.29
9	198.68	171.46	761.06	410.70
10	198.84	174.77	775.07	414.65
..				
39	199.97	199.95	881.62	442.46
40	199.99	199.99	881.71	442.50

The market undergoes a kind of "phase change," from parallel processing in the first hour, to serial processing once most offers are being held…

Table 3: The Telephone Market with 7 Hours Enforced Termination Time

Results of 100 simulations for each of the following cases

	The Psych Model	20 Students May Hold Two Offers Once for Two Hours	Every Student May Hold Two Adjacent Offers Until One Hour Before the Deadline	Every Student May Hold Two Adjacent Offers Until the Deadline	Every Firm First Issues Offers to Students Who Like It Best
Mean time to termination (standard deviation)	**7:43 (0:22)**	7:53 (0:10)	8:01 (0.10)	8:08 (0:07)	7:36 (0.37)
Mean time by which 90% of students have received at least one offer	**1:02**	2:11	2:22	2:33	0.57
Mean time by which 99% of students have received at least one offer	**5:07**	7:06	7:37	7:51	5:23
Mean # of blocking firms (standard deviation)	**1.58** (0.74)	**3.25** (1.26)	**6.32** (1.61)	**12.77** (2.27)	**2.34** (1.02)
Mean # of blocking students (standard deviation)	**16.67** (7.73)	**29.88** (9.80)	**48.74** (11.26)	**77.76** (11.57)	**15.74** (8.06)
Mean # of unmatched students	**0.88**	1.09	1.52	1.69	0.78
Mean # of unmatched firms	**0.87**	1.07	1.41	1.52	0.78

Table 4: Hourly Progress of the Psych Model Telephone Market

Mean results based on 100 simulations

Hour	# Students Who Have Received at Least One Offer	# Students Who Have Received an Offer from the Firm to Which They Will Ultimately Be Matched	# Offers that Have Been Made	# of Offers that Have Not Been Rejected Immediately
0	0.00	0.00	0.00	0.00
1	178.47	104.13	400.08	2.78.06
2	191.24	140.52	531.96	333.90
3	194.83	161.12	602.36	360.04
4	196.50	174.59	648.58	375.70
5	197.41	184.64	681.79	386.80
6	198.02	192.46	707.38	395.01
7	198.37	198.37	727.89	400.99
8	199.11	199.11	786.35	401.73
9	199.12	199.12	**786.79**	401.74

Recall that when the deferred acceptance algorithm was allowed to run its course, on average **882** offers were needed.

Number of Students Who Match with Choice i (Stochastic Dominance)

Mean results of 100 simulations for each of the following cases

Choice I to which students match	**The Medical Model**	**The Psych Model**	**Psych Model, 20 Students May Hold Two Offers for Two Hours**	**Psych Model, Students May Hold Two Adjacent Offers 'til 1 Hour Before the Deadline**	**The Psych Model & Every Student May Hold Two Adjacent Offers Until the Deadline**	**The Psych Model & Firms First Issue Offers to Students Who Like Them Best**
1	50.50	41.02	36.24	30.61	23.98	42.57
2	36.78	31.57	28.74	24.84	20.01	32.05
3	27.62	25.54	24.12	22.06	19.07	25.33
4	20.97	20.74	20.07	18.49	16.55	20.84
5	16.17	*16.88*	*16.50*	16.24	15.10	16.38
6	11.75	13.21	13.58	13.59	13.19	12.67
7	9.03	10.57	11.14	*11.78*	*11.43*	10.17
8	6.53	8.22	8.88	9.60	10.50	8.20
9	5.20	6.62	7.33	8.39	9.22	6.79
10	3.93	5.40	6.29	7.14	8.42	4.85
11	2.91	4.30	5.20	6.29	7.69	4.60
12	2.30	3.63	4.50	5.95	7.31	3.55

13	1.17	2.70	3.63	4.58	5.92	2.70
14	1.27	2.30	2.94	3.95	5.34	2.11
15	0.86	1.53	2.34	3.26	5.41	1.72
16	0.80	1.44	2.13	3.12	4.63	1.42
17	0.50	1.04	1.53	2.69	4.23	0.95
18	0.44	0.85	1.31	2.14	3.63	0.98
19	0.37	0.76	1.23	2.07	3.93	0.83
20	0.35	0.80	1.21	1.69	2.75	0.51
u	0.01	0.88	1.09	1.52	1.69	0.78

u = Unmatched

Table 6: Medical and Psychology Market Simulations: Varying the Correlation of Preferences

Students Have Preferences Over All 50 Firms (Results of 100 Simulations)

Preferences	Case 1 Students have uncorrelated random preferences **Firms have uncorrelated random preferences**		Case 2 Students have uncorrelated random preferences **Firms have identical preferences**		Case 3 Students have identical preferences **Firms have identical preferences**		Case 4 Students have identical preferences **Firms have uncorrelated random preferences**	
	Medical Market	Psych Market	Medical Market	Psych Market	Medical Market	Psych Market	Medical Market	Psych Market
Mean* time to termination (standard deviation)	22.53 (12:03)	8:39 (0:43)	25.09 (0:45)	18:10 (0:14)	20:46 (0:18)	17:12 (0:17)	13.16 (2.18)	8:29 (0:32)
Mean time by which 90% of students have received an offer	**1:09**	**1:09**	22:06	16:10	18:51	15:12	**1:18**	**1:18**
Mean time by which 99% of students have received an offer	7:02	6:21	24:50	17:57	20:36	16:58	7:53	6:52
Mean number blocking firms	0	2.23 (.85)	0	47.75	0	37.1 (2.05)	0	.68 (.68)
Mean number blocking students	0	31 (12.83)	0	151.31 (3.71)	0	156.13 (7.48)	0	1.72 (2.23)

Table 7: The Medical Model Telephone Market with Varying Number of Firms and Infinitely Many Phones (200 students and 200 positions to be filled)

Results of 100 Simulations

Number of Firms	2	5	10	20	50	100	200
Mean time to termination at a stable outcome (standard deviation)	1:20 (0:24)	3:40 (1:22)	5:27 (2:34)	7:17 (3:27)	8:47 (3:19)	10:31 (5:41)	11:13 (4:49)
Median time to termination	1:20	3:33	4:46	6:23	8:19	9:14	10:07
Mean time by which 90% of students have received an offer	0:10	0:21	0:27	0:31	0:34	0:35	0:35
Mean time by which 99% of students have received an offer	0:40	1:32	1:59	2:32	3:10	3:22	3:58
Longest time to termination	3:05	7:45	15:08	24:14	18:39	30:51	26:52
Shortest time to termination	0:40	1:26	2:32	2:04	3:52	2:53	3:29

Conclusions

Markets in which offers must remain open for a specified time (even if it is short):

- Experience congestion
- Undergo phase changes—from parallel processing to serial processing
- Give firms an incentive to think about not only how much they like a worker, but how much the worker likes them.

Signaling can help this process work: students were asked for signals, and they influenced offers.

A critical element of a market is its *effective* length: how many possible transactions can be explored through the process of making offers. The effective length of the psychology market *increased* as its *duration* decreased from five days to one…

Methodological remarks:

Economists are justly skeptical of computational results if they aren't transparent, or robust.

But here was a case in which the available theorems were of the form: "if 7 hours is long enough, the market will have a chance to behave like a centralized market, otherwise not." So the question was, given that offers and responses are fast, is 7 hours long enough?

Computation was the only way I knew to find out.

And lots of robustness checks help to understand the results.

Postscript:
Since 1999, APPIC has run a centralized match, using the Roth-Peranson algorithm.

The programs in this match have the most variable and complex requirements and preferences, and one of the services that Eliot Peranson offers to them is that he will help them state their preferences in ways that the algorithm recognizes (i.e. in terms of lists of responsive preferences for sub-programs whose positions may revert from one to another…)

Some of the examples he's encountered suggest that he's *mostly* seeing substitutable preferences…

Example 1: Bilingual

	Bilingual
1. George	No
2. Mary	Yes
3. Greg	No
4. Sally	Yes
5. Ruth	No
6. Frank	No
7. Jane	No
8. Bob	Yes

- 3 positions
- At least 1 bilingual
- More is acceptable
- Want Bob only if necessary as bilingual
- Prefer to have unfilled position if no bilingual match

List A (Bilingual) 1 position
1—Mary
2—Sally
3—Bob

List B 2 positions
1—George
2—Greg
3—Sally
4—Ruth
5—Frank
6--Jane

Example 2:Research Interest

- 4 positions, 9 applicants
- Prefer 2 with interest in research and 2 with no research interest
- Wants to fill all positions
- (In the gastroenterology match, research and non-research positions are formally separated, so e.g. applicants can also have preferences over them…)

List A (Research) 2 positions	List B 2 positions
Lynn	David
Sandra	Mark
Rahim	Rhonda
Ellen	Boris
	Bella
	Ellen
	Rahim

Any position not filled
on List A reverts to List B

Example 3:Variable Capacity

- Firm has 15 acceptable applicants
- Wants to match with 3 applicants
- Will take as many of the top 5 applicants as it can get

List A 5 Positions	List B 0 Positions	List C 0 Positions
A1	A6	No Ranks
A2	A7	
A3	.	
A4	.	
A5	A15	

Positions A1-A3 revert to B

Any other unfilled positions revert to C (which has no acceptable workers)

Example 4: List of Alternates

- 3 positions
- Prefer 1 applicant best suited for each age group of clients

  Submit separate list for each age group

- If one or more positions from separate lists do not fill, requirements might be more complex

	Pre-School	Grade School	Teenager
Joe			Best
Steve	No	No	Very Good
Wendy	Acceptable	Acceptable	Very Good
Beth		Best	
Sam	Good	Very Good	Good
Farah	Good	Very Good	Good
Karen	Best		
Ali	Very Good	Good	Good
Brandy	Acceptable	Acceptable	Acceptable
Gary	Acceptable	Acceptable	Acceptable

List A (Teen) 1 position

Joe

Steve

Wendy

List B (Grade) 1 position

Beth

Sam

Farah

Lists A, B, C all revert to List D

List C (Pre) 1 position

Karen

Ali

List D (Alternates) 0 position

Sam

Ali

Farah

Brandy

Gary

Wendy