College Admission Mechanism and Matching Quality: Evidence from China*

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Abstract:

We compare four alternative matching mechanisms between students and colleges that differ in terms of the timing of students' preference submission (pre- or post-exam) and the availability of parallel options. Pre-exam mechanisms compel students to submit their preferences when their exam scores are uncertain; mechanisms without parallel options encourage students to manipulate their preferences. However, pre-exam mechanisms without parallel options (the traditional mechanism) can be ex-ante fairer or more efficient than the other mechanisms, although they are worse ex-post. Our empirical analysis uses a dataset from a top-ranked school of a university in China and the identification is based on the temporal change in the mechanisms that vary across provinces. We find that students admitted under the traditional mechanism have, on average, lower college entrance exam scores than students admitted under the other mechanisms. However, the former exhibits similar or even better college academic performance than the latter. These findings are consistent with our theory and imply that students with higher academic aptitude or stronger preference for a premier school fare better under the traditional mechanism. This study is one of the few studies that use real-world data to identify the causal effects of matching mechanisms on matching quality.

Keywords: College admission system; School choice mechanism; Matching quality; Preference submission; Parallel options

JEL Classification: C78, D61, D78, I28

I. Introduction

China's college admission process is one of the largest and most influential matching problems in the world. In 2009, around 10 million high school graduates competed for the slots available in colleges. Although the admission rate has reached 63% in 2009, admission into universities, especially high-quality universities, remains a much coveted opportunity.[1] This is a typical one-sided and multi-to-one matching problem: if it is not possible for all students to go to their most desired colleges, how should space in different colleges be allocated?

The school choice literature usually focuses on three properties of a mechanism to see whether it is socially desirable: fairness (or stability), efficiency, and strategy-proofness. Recent studies highlight that when there is uncertainty about the priority order of schools on students, the fairness or efficiency of a mechanism depends on whether we evaluate the mechanism from an ex-ante perspective or from an ex-post perspective (Abdulkadiroglu, Che, and Yasuda, 2009; Featherstone and Niederle, 2008). Literature also favors strategy-proof mechanisms that proof preference manipulation, yet some researchers found strategy-proofness may have its costs (Abdulkadiroglu, Che, and Yasuda, 2009; Budish and Cantillon, 2011).[2] These discussions are related to a general question about the role of uncertainty and preference manipulation in the comparison of matching mechanisms. This question is also important for other matching problems such as course allocation, high school or graduate school enrollment, and the assignment of coupons.

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[1] In 2009, 38% of college applicants were admitted by universities and 3% were admitted by the top 73 universities owned by the Education Department (Educational Statistics Yearbook of China, 2010).

[2] In particular, the Boston mechanism has been recognized as ex-post inferior to the Deferred Acceptance (also called Gale-Shapley) and the Top Trading Cycles mechanism (or Serial Dictatorship as its special case) because it is inefficient and not strategy-proof (Abdulkadiroğlu and Sonmez, 2003; Ergin and Sonmez, 2006). Yet when there are uncertainties of schools' priorities on students or asymmetric information of students' preferences on schools, the Boston mechanism may be ex-ante more efficient and fairer even though it is not strategy-proof (Abdulkadiroglu, Che, and Yasuda, 2009; Featherstone and Niederle, 2008). Budish and Cantillon (2011) find that the course allocation at Harvard Business School is manipulable yet performs better than its widely studied strategy-proof alternatives.

However, there are few empirical studies concerning the discussions. Our paper illustrates both theoretically and empirically that a Boston-like mechanism, in which students face uncertainties on schools' priority and manipulate preference, can perform better than other strategy-proof mechanisms by the standard of fairness or efficiency from an ex-ante view, although it is not so from an ex-post view. We take advantage of China's college admission system that shares the common features of a school choice problem and has experienced numerous policy changes so that we can conduct empirical comparisons over alternative mechanisms.

More specifically, China's college admission system is comprised of two stages. Stage one is a national college entrance exam called the CEE or *gaokao* in Mandarin. Stage two involves a matching mechanism that assigns students to colleges on the basis of students' CEE scores and their reported preferences. Although the core framework has remained stable, numerous policy changes have taken place with the goal of improving its efficiency and equity. One policy change is related to the timing of preference submission, which was changed from before the exam to either after the exam but prior to the release of CEE scores or after the students have learned of their scores. When students need to submit preferences prior to the release of scores, they are confronted with uncertainties regarding the schools' priority orders on students, which are almost entirely determined by the CEE scores. Another important policy change is the shift from a matching procedure without parallel options to one with parallel options. In a matching procedure without parallel options, the admission priority is based on reported preference first, then on the CEE score, whereas in a matching procedure with parallel options, priority is based first on the CEE score and then on reported preference. This implies that mechanisms without parallel options emphasize less on the one-shot exam score and more on the reported preference, which increases students' incentive to manipulate their preferences.

This paper examines four typical matching mechanisms along the path of recent reforms: (i) preference submission before the exam and without parallel options (pre-exam-no-parallel), also labeled as the traditional mechanism; (ii) submission before the exam and with parallel options (pre-exam-with-parallel);[3] (iii) submission after the release of scores without parallel options (post-score-no-parallel); and (iv) submission after the release of scores with parallel options (post-score-with-parallel).

Borrowing from the school choice literature and building our own examples that are tailored to China's background, we theoretically illustrate that compared with the traditional mechanism, the other three mechanisms are more likely to generate ex-post efficient and fair matching outcomes in their Nash equilibria. In other words, the other three mechanisms are more likely to match students having high *realized* CEE scores with good schools, for which all students have a high preference. Moreover, the traditional mechanism is not a truth-telling mechanism while two of the other three mechanisms are free of preference manipulation. However, the traditional mechanism is more likely to achieve ex-ante efficient or fair matching outcomes compared with the other three mechanisms. That is, the traditional mechanism is more likely to match good schools with students who possess either a high ability (thus, higher *expected* CEE scores) or a strong preference for good schools.

The explanation for these theoretical results is intuitive; specifically, under the traditional mechanism, students who expect low CEE scores or exhibit low interest in good schools will give up applying to such schools, through manipulation of their true preferences. This decision takes these students out of the competition for admission into good schools regardless of how high their ex-post CEE scores are. Consequently, the slots of good schools are "reserved" for students who expect high CEE scores or have high interest in these schools,

[3] The pre-exam-with-parallel mechanism is only analyzed theoretically. This mechanism is rarely seen in practice because the post-exam reform was introduced prior to the reform on parallel options. In the empirical analysis, we consider the mechanism that has no parallel options and asks students to submit their preference after the CEE but before the release of the CEE scores.

even if these students fail to obtain a high CEE score ex-post.[4]

Our theoretical predictions are then tested using a unique dataset from one of the best schools within a top-ranked university in China. In particular, we examine how the characteristics of students admitted by this top-ranked school are affected by alternative matching mechanisms. We compare the CEE scores and college academic performance of the students admitted under various mechanisms and consider college academic performance as a better indicator of students' intrinsic academic aptitude or their interest in the school than their CEE score. The temporal and provincial variations in matching mechanisms are exploited to identify the causal effects. Our results are largely consistent with the theoretical prediction: students admitted under the traditional mechanism have lower CEE scores than students admitted under the post-exam mechanisms. However, students admitted under the traditional mechanism exhibit similar or even better college academic performance than those admitted under the post-exam mechanisms.

This study is complementary to the school choice literature that focuses on the theoretical analyses of the efficiency and fairness of matching mechanisms. Among the few empirical studies in school choice literature, most works are based on experimental data (Chen and Sonmez, 2006; Featherstone and Niederle, 2008; Pais and Pinter, 2008; Klijn, Pais, and Corsatz, 2010). A few studies have used real-world data in the US, including Abdulkadiroglu et al. (2006), who focus on the adoption of the *Boston mechanism* in the Boston area, as well as Abdulkadiroglu, Pathak, and Roth (2009), who simulate and compare the matching outcomes of different mechanisms based on the preferences reported by the applicants to high schools in New York City.

Our empirical study is based on real-world data and is distinguishable from previous studies in two aspects. First, we observe both students' CEE scores and their college

[4] The dark side of the traditional mechanism is that it may be riskier for these students because they can end up attending a college of poor quality if their scores are too low to be eligible for admission into the top schools they have ex-ante listed as their first choice.

academic performance, which enables us to evaluate the mechanisms from both the ex-ante and the ex-post perspectives. Second, to measure matching quality, we focus on the matching results for a single top school, taking advantage of the appropriate assumption in China's context that all students tend to exhibit the strongest preference for such a school. This approach vastly simplifies the complicated issue of measuring matching quality; otherwise, we would need to consider the entire matching involving a large number of schools and students, employing relatively arbitrary conjectures about students' preference order for all schools.

Our work is also related to two other branches of literature. One branch is about the correlation between high school scores and college academic performance (for a review, see Rothstein, 2004). Our results indicate that, for top schools, the correlation between CEE scores and college academic performance depends on the matching mechanism. The other branch is the empirical research on the determinants of the quality of university admissions. For example, Jensen and Wu (2010) analyze data from a single college in the US and find that students admitted through the Early Decision Plan program perform worse than those admitted through regular procedures. Our study demonstrates that, even for those admitted through regular procedures, certain aspects of the admission system continue to affect the quality of students.

Finally, the design of matching mechanism for college admissions is important for families who are concerned about what type of college their children are admitted to. It also matters for China's economic growth because such growth depends heavily on innovations that are closely correlated with the quality of college students. School matching in China may also be interesting for other countries, not only because of the increasing global influence of the Chinese labor market and the country's economic growth, but also because of the increasing number of Chinese college students going abroad to pursue graduate studies or work.[5]

The rest of the paper is organized as follows. Section II introduces the institutional background and gives a formal description of the four typical matching mechanisms in China's college admission system. It then defines the concepts of ex-ante and ex-post efficiency and fairness in the context of China's system. Section III theoretically discusses how different matching mechanisms can affect matching welfare. Section IV introduces the econometric models and describes the data and the variables. Section V presents the regression results. Section VI concludes the paper.

II. College Matching Mechanisms in China

A. Institutional Background

Since China rebuilt its college admission system in 1977, college applicants have been required to report their preferences for colleges (and majors) on an application form before taking the CEE.[6] Since the late 1990s, however, an increasing number of provinces have shifted to a mechanism that requires students to submit their application forms after taking the CEE. Depending on the province, students turn in their application forms either prior to or after the release of the CEE scores. Table 1 summarizes the timing of preference submission in all the provinces after 1999. In 1999, five provinces maintained the traditional system of submitting preferences before the exam. By 2009, only two provinces maintained this practice. The system featuring submission after the release of test scores rapidly gained popularity, being implemented in 5 provinces in 1999 and 23 provinces by 2008. Several provinces, such as Beijing, Jilin, and Guangdong, alternated between systems.

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[5] The number of Chinese students going abroad to pursue graduate studies has increased by 30% annually since 1999, reaching 0.28 million in 2010 (Educational Statistics Yearbook of China, 2010).

[6] During the college admission process, colleges are categorized into different tiers. Colleges in the first tier, which are the best colleges, admit students first, followed by colleges in the second tier, and so on (Davey et al., 2007). Each tier contains four to six choices of colleges, with three to six choices of majors (including an option of "any major") for each college. When colleges admit students, they match students with majors using the procedure similar to the matching between students and colleges. To simplify the current study, we focus only on the matching between colleges and students.

Another feature of the system concerns parallel options. No parallel options are offered in the traditional mechanism, which corresponds to the *Boston mechanism* (BOS) —one of the most commonly discussed mechanisms in literature (a formal description will be given in the next sub-section). Although the mechanisms with parallel options have been only introduced in recent years, they have become increasingly popular in China. All provinces except Hunan and Jiangsu introduced parallel options after 2007.[7] If students can apply to as many schools as they want, the mechanism is called a mechanism with complete parallel options, which corresponds to the top trading cycles (TTC) or score-ordered serial dictatorship (SD) mechanism in the school choice literature (also described in the next sub-section).[8]

One specific property of China's college admission procedure is the so-called *acyclic* property of schools' priority order on students. More specifically, the schools' priority orders on students are solely determined by the CEE scores. That is, students with higher test scores are always preferred; hence, all schools essentially have the same priority order on students.

For the theoretical analyses, we focus on four typical mechanisms: (i) preference submission before the exam without parallel options (pre-exam-no-parallel); (ii) submission before the exam with complete parallel options (pre-exam-with-parallel); (iii) submission after the release of scores without parallel options (post-score-no-parallel); and (iv) submission after the release of scores with complete parallel options (post-score-with-parallel). The first mechanism is the traditional system whereas the last mechanism is the target model for the current reform. There are two other mechanisms in practice: submission after the exam but before the release of scores with or without parallel options (post-exam-pre-score-no/with-parallel). These two mechanisms fall between the

[7] Parallel options are sometimes introduced only in some tiers of colleges. The number of choices students can submit is also limited.

[8] TTC and SD are different mechanisms. However, when all the schools have the same priority ranking of students, which is true in China, these two mechanisms are equivalent (see Abdulkadiroglu and Sonmez, 2003).

pre-exam mechanisms and the post-score mechanisms. In addition, for the parallel options, the number of parallel options is considerably smaller than the number of colleges in practice. This situation falls between “no parallel option” and “the complete parallel options”.

B. Mechanism Description and Evaluation

Mechanism Description

Pre-exam-no-parallel or Traditional Mechanism

The “pre-exam-no-parallel” mechanism works according to the following steps:

Step 1: Students submit their preference list that ranks their choices, including their first choice, second choice, third choice, and so on.

Step 2: Students take the CEE and receive their exam scores.

Step 3: Each college considers the students who ranked the college as their first choice and ranks these students based on their CEE scores (from high to low). The college continues to admit students as long as its predetermined quotas have not been filled.

Step 4: If there are remaining spaces in the college after step 3, the college considers the students who ranked it as their second choice. Again, the college ranks these students according to their CEE scores and admits students as long as it has not filled its predetermined quotas.

Step 5: If there are remaining spaces in the college after step 4, the college considers the students who listed it as their third choice.

The procedure continues until all colleges have filled their quotas or all colleges listed by every student have been considered. Students who are not admitted at the end are not admitted by any college.

Pre-exam-with-parallel Mechanism

The “pre-exam-with-parallel” mechanism has the following steps:

Steps 1 and 2: Same as steps 1 and 2 in the “pre-exam-no-parallel” mechanism.

Step 3: Match the student with the highest CEE score with his/her preferred colleges. This student is matched with his/her top-ranked college as long as the college still has spaces available. If not, the student's second-ranked college is considered. This continues until the student is admitted by one of the colleges on his submitted list or until all colleges that the student has listed have filled their quotas.

Step 4: Match the student with the second highest CEE score with his/her preferred colleges, following the same process as in step 3.

Step 5: Match the student with the third highest test score with his/her preferred colleges, following the same process as in step 3.

The procedure continues until all students have been considered or all colleges have filled their quotas.

Post-score-no-parallel Mechanism

The "post-score-no-parallel" mechanism includes the following steps:

Step 1: Students take the CEE and receive their exam scores.

Step 2: Students submit their preference list.

Step 3 and further: Same as step 3 and further in the "pre-exam-no-parallel" mechanism.

Note that this mechanism corresponds perfectly to the BOS mechanism in the school choice literature.

Post-score-with-parallel Mechanism

The "post-score-with-parallel" mechanism proceeds as follows:

Steps 1 and 2: Same as steps 1 and 2 in the "post-score-no-parallel" mechanism.

Step 3 and further: Same as step 3 and further in the "pre-exam-with-parallel" mechanism.

If students can apply to as many schools as they want, this mechanism corresponds to the TTC/SD mechanism in the school choice literature. Furthermore, when all the schools have the same priority order on students, which is true in China, the mechanism functions equivalently to the Gale-Shapley (GS) or deferred acceptance (DA) mechanism.

Mechanism Evaluation

To evaluate the welfare of different matching mechanisms, we adopt the ex-ante and ex-post efficiency and fairness (stability) concepts from the school choice literature. To simplify, we assume that, before the exam, every student knows the distribution of his/her CEE score and that the distribution is independent across students. The concept of strategy-proofness is also described.

Efficiency

Definition 1.1 (Ex-post Efficiency). A matching mechanism is ex-post efficient if, for any students' preferences and *for any realization of the score distribution of all students*, the mechanism always implements in its Nash equilibrium a matching outcome that is Pareto efficient. That is, there is no other matching outcome where at least one student is better off and all other students are no worse.

Definition 1.2 (Ex-ante Efficiency). A matching mechanism is ex-ante efficient if, for any students' preferences and *for any score distribution of all students*, the mechanism always implements in its Nash equilibrium a *distribution* of matching outcome that is ex-ante Pareto efficient. That is, there is no other matching outcome distribution where at least one student gets higher *expected* utilities and no other students have lower *expected* utilities.

In this context, the expected utility of a student is based on his/her CEE score distribution before the exam: Given the students' strategies, the expected utility is averaged over all potential realizations of score distribution of all students.

Fairness/Stability

Definition 2.1 (Ex-post Fairness/Stability). A matching mechanism is ex-post fair/stable if, for any students' preferences and for any realization of the score distribution of all students, the mechanism always implements in its Nash equilibrium a matching outcome that is ex-post fair/stable. That is, no such situation exists where at least one student strictly prefers a school to the one admitting him/her, and the school has not filled its quota or has admitted other students with lower exam scores.

Definition 2.2 (Ex-ante Fairness/Stability). A matching mechanism is ex-ante fair/stable if, for any students' preferences and for any realization of the score distribution of all students, the mechanism always implements in its Nash equilibrium a matching outcome that is ex-ante fair/stable. That is, no such situation exists where at least one student strictly prefers a school to the one admitting him/her, and the school has not filled its quota or has admitted other students with lower ***expected*** exam scores.

For ex-ante efficiency, we only consider the expected utilities averaged over all potential realizations of score distributions. This means that for some realizations of score distributions, students can be worse off in an ex-ante efficient matching outcome than in some other outcomes. In contrast, ex-ante fairness is evaluated for every realization of score distributions because students with higher expected scores should never be treated unfairly in an ex-ante fair matching outcome. Hence, an ex-ante fair matching mechanism protects students with high expected scores in the sense that even if they fail to achieve a high score on the exam, they can still be admitted by a good school.

Strategy-proofness

Definition 3 (Strategy-Proofness). A matching mechanism is strategy-proof if, for any student's preferences, truly reporting their preference for schools is a (weakly) dominant strategy for all students.

The advantage of strategy-proofness is that students can save time on preference manipulation. In addition, students may have different levels of rationality for such a manipulation; hence, strategy-proofness helps avoid the unfairness caused by rationality disparities.

III. Theories and Hypotheses

This section presents the theories on welfare properties of the previously described four typical matching mechanisms in China, followed by the hypotheses for the empirical testing. Our theory is primarily based on the correspondence between these four mechanisms and the mechanisms discussed in the school choice literature.

Generally, a school choice problem is a one-sided, multi-to-one matching problem. Every school can admit more than one student, but every student can only be admitted by one school. The priority order of schools on students is predetermined and known by students, such that there is no strategic play on the school's side. Students report (often strategically) their preferences for schools. Afterward, a matching mechanism (or admission procedure) is used to match the students with schools according to the students' reported preferences. One unique feature of China's system is that schools' priority order on students satisfies the *acyclic* property, since all schools essentially have the same priority ranking of students, which is the CEE score.[9]

A. General Theories

Our first general theory relates to the two post-score mechanisms. We borrow from existing theories because these two mechanisms correspond perfectly to the BOS mechanism and the TTC/SD mechanism respectively in the literature.[10]

Proposition 1: (1) The post-score-with-parallel mechanism is ex-post efficient, ex-post fair, and strategy-proof, and the matching implemented in Nash equilibria (NE) is unique. (2) The post-score-no-parallel mechanism implements in NE a unique matching that is ex-post efficient and ex-post fair; however, this mechanism is not strategy-proof.

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[9] See Appendix A for a formal definition of acyclicity and its relation to the Chinese admission system.

[10] Theories on the BOS mechanism are discussed in Abdulkadiroglu and Sonmez (2003), Ergin and Sonmez (2006), and Haeringer and Klijn (2009). Theories on the TTC/SD mechanism are discussed in Abdulkadiroglu and Sonmez (2003) and Kesten (2006).

For the proof, see Appendix B.

Our second general theory relates to the pre-exam-with-parallel mechanism. This mechanism is very similar to the TTC/SD mechanism, except that students do not know their CEE scores when they submit their preferences. This situation leads directly to uncertainty regarding the schools' priority order on students when submitting preferences. However, the uncertainty does not affect the strategies of the students, in the sense that truth telling is still a dominant strategy (Abdukadiroglu and Sonmez, 2003). Therefore, the conclusions for the TTC/SD mechanism can be carried over to the pre-exam-with-parallel mechanism.

Proposition 2: Under the pre-exam-with-parallel mechanism, truth telling is the students' weakly dominant strategy. Thus the mechanism is strategy-proof. The mechanism also implements the (unique) ex-post efficient and ex-post fair matching in this weakly dominant strategy equilibrium.

For the proof, see Appendix C.

Propositions 1 and 2 state that these three mechanisms (not the traditional or pre-exam-no-parallel mechanism) implement practically the same matching in their NE, which is ex-post efficient and fair. These propositions also show that uncertainty and preference manipulation are both necessary for having a matching outcome different from the unique ex-post efficient and ex-post fair outcome. We discuss the ex-ante welfare properties of these three mechanisms and compare them with the traditional mechanism in the next sub-section. We will show that there are trade-offs between ex-ante and ex-post efficiency and fairness.

B. Two Examples for Ex-ante Evaluations

For the pre-exam-no-parallel or traditional mechanism, no general theories exist in literature. The traditional mechanism is different from the BOS mechanism only in that students face uncertainties regarding schools' priority orders on students or CEE scores when they submit their preferences when they submit their preferences. Recent literature highlights that when uncertainties arise, the BOS mechanism *might* be superior to other mechanisms in terms of ex-ante efficiency and/or fairness (see Abdulkadiroglu, Che, and Yasuda, 2009; Featherstone and Niederle, 2008; for China's case, see Nie, 2007; Zhong et al., 2004). However, these results are only concerned with certain special cases such as when each school has an equal number of slots or when each student's preference follows the same uniform distribution ex-ante. These cases are inapplicable to China's case. Therefore, we construct two examples to illustrate that the traditional mechanism *can* be superior to other mechanisms from the ex-ante perspective.

Example 1: Ex-ante fairness

Three schools are considered and labeled as 1, 2, and 3. Each school admits one student based on students' test scores. Three students, A, B, and C, have the same cardinal preferences for the schools—namely, all of them have the highest preference for school 1, followed by schools 2 and 3, as shown in the following table.

	School 1 (good)	School 2 (middle)	School 3 (bad)
Student A	100	67	25
Student B	100	67	25
Student C	100	67	25

All three students have the same order of preference (ordinal preference); hence, all the admission results are equally ex-post efficient. All the admission results are also ex-ante efficient because of homogenous *cardinal* preferences. Thus, in this example, the focus is on the ex-ante and ex-post fairness.

To introduce uncertainties in test scores, we assume that each student has a two-thirds probability of performing normally in the CEE and a one-third probability of exhibiting unusually poor performance. This probability is independent among students. When all three students perform normally or unusually poorly, their test scores follow the normal or expected rank: student A>student B>student C. When a student exhibits unusually poor performance while the others do not, then he/she ranks lower than the student positioned next in the expected rank. However, regardless of their performances, student A always scores higher than student C, who is far behind A according to the expected score rank. For example, when the performance of student A (B, C) is unusually poor (normal, normal), their scores follow the ranking: student B>student A>student C. The distribution of score ranks can be calculated as follows: (A, B, C) has a probability of 15/27; (A, C, B) has a probability of 6/27; and (B, A, C) has a probability of 6/27.

In this example, the traditional mechanism has a unique Nash equilibrium matching result: Student A is admitted by school 1, student B is admitted by school 2 when he/she has a higher score than student C and by school 3 otherwise, and student C is admitted by the school left on the list. The equilibrium strategy is that student A lists school 1 as his/her first choice, and both students B and C list school 2 as their first choice. Each student can list any remaining school as their second and third choice. (For the proof, see Appendix D.) Based on propositions 1 and 2, we know that the three mechanisms other than the traditional mechanism implement ex-post fair matching outcome—namely, students with higher ex-post test scores are assigned to better schools. For example, if the score rank is A>C>B, then under all these three mechanisms, the matching outcome is that student A is admitted by school 1, student C by school 2, and student B by school 3.

The following table illustrates the matching results under different score realizations and different mechanisms for this example. From the ex-ante point of view, the fair result is A:1, B:2, C:3. That is, student A goes to school 1, student B goes to school 2, and student C goes to school 3 because the expected CEE score follows the rank A>B>C. The traditional mechanism has a higher probability (15/27+6/27) of yielding this result than all the other three mechanisms (probability=15/27). Therefore, the traditional mechanism is ex-ante *fairer*, although it is not an ex-ante *fair* mechanism in this example.

Score Rank	Probability	Matching result under the traditional mechanism	Matching result under the other three mechanisms
(A, B, C)	15/27	(A:1, B:2, C:3)	(A:1, B:2, C:3)
(A, C, B)	6/27	(A:1, B:3, C:2)	(A:1, B:3, C:2)
(B, A, C)	6/27	(A:1, B:2, C:3)	(A:2, B:1, C:3)

These findings can be summarized by the following proposition.

Proposition 3: The pre-exam-no-parallel or traditional mechanism can implement in its Nash equilibrium an ex-ante fairer matching outcome than the other three mechanisms.

Example 2: Ex-ante efficiency

Three schools (i.e., 1, 2, and 3) are again considered, with each school admitting one student according to test scores. Three students (i.e., A, B, and C), still have the same ordinal preferences, that is, school 1>school 2>school 3. However, the intensity of their preferences for the schools differs. Compared with the other two students, student C perceives schools 1 and 2 to be more similar. The students' cardinal preferences are shown in the table below.

	School 1 (good)	School 2 (middle)	School 3 (bad)
Student A	100	45	25
Student B	100	45	25
Student C	60	45	25

To focus on ex-ante efficiency, we assume that all three students have the same academic aptitude or the same expected test scores; thus, all the matching outcomes are equally ex-ante fair. Furthermore, any matching outcome in which all students are matched is ex-post efficient, because all students have the same preference orders.

The traditional mechanism is shown to yield a unique Nash equilibrium matching outcome: Students A and B have an equal probability of going to schools 1 or 3. Student C definitely goes to school 2. The equilibrium strategy is that both students A and B list schools 1, 2, and 3 as their first, second, and third choices, respectively. Student C lists school 2 as his/her first choice and any remaining school as his/her second and third choices. (For the proof, see Appendix E.) For the other three mechanisms, the equilibrium matching can be derived from propositions 1 and 2, as in example 1. That is, the student with the highest realized CEE score is admitted by school 1, the second highest is admitted by school 2, and the lowest is admitted by school 3. From the ex-ante point of view, each student has an equal probability of going to any of the three schools.

The following table shows the calculation of each student's expected utility in equilibrium under all four mechanisms. For all students, the expected utilities under the traditional mechanism are greater than those under the other three mechanisms. Thus, this mechanism is the most ex-ante efficient among the four mechanisms.[11]

Expected utilities of students		
	Traditional/Pre-exam-no-parallel	The other three mechanisms
Student A	62.5	170/3≈56.7
Student B	62.5	170/3≈56.7
Student C	45	130/3≈43.3

The primary conclusion from this example can be summarized as follows.

Proposition 4: The pre-exam-no-parallel or traditional mechanism can implement in its Nash

[11] The traditional mechanism is less ex-post fair than the other three mechanisms because student C loses the opportunity to attend school 1 even if he/she obtains a high CEE score.

equilibrium a more ex-ante efficient matching than the other three mechanisms.

Intuitively, the traditional mechanism introduces uncertainties in terms of the types of schools for which students are qualified when they submit their preference list. The uncertainty forces students to contemplate their preference *intensities* when filling-in their application forms. More specifically, given their risk attitude, students who have lower preference intensities for high-quality schools are more likely to give up such schools to secure a slot in schools of modest quality. As a result, students who exhibit high-intensity preference for premier schools have better chances of attending these schools. Social welfare is thereby improved. In contrast, under the other three mechanisms, uncertainties on scores are fully resolved when students submit their preferences.[12] The school each student attends in the equilibrium is fully determined by score ranks and preference orders, while preference intensities are insignificant.

C. Testable Hypotheses for Top Schools

We now consider how to test the four propositions. Ideally, for each matching mechanism, we should examine the quality of the matching outcome involving all schools and students. This requires information on all students' actual preferences, scores, and matching results. Researchers have formulated many different ways to evaluate the matching quality based on different assumptions, mainly through laboratory experiments.[13]

In the present study, a different approach is employed by focusing exclusively on a subset of students who are matched to a top school in a premier university. This top school is one of the most preferred schools by *all* students. By focusing exclusively on the matching

[12] For the pre-exam-with-parallel mechanism, although there are uncertainties when submitting preferences, truth telling is a dominant strategy; hence, uncertainties do not affect students' strategies.

[13] To measure efficiency, Chen and Sonmez (2007) construct cardinal utilities of students with regard to different schools in experiments and calculate the average utility of participants under different mechanisms. Pais and Pinter (2008) adopt the ratio of the sum of all the participants' observed utilities to the sum of "ideal" utilities under Pareto efficient matches. Featherstone and Niederle (2008) benefit from the transparency of small-scale experiments to calculate more measures for efficiency. To measure fairness, Calsamiglia, Haeringer, and Klijn (2009) and Abdulkadiroglu, Pathak, and Roth (2009) count the numbers of blocking pairs in a large-scale experiment. Pais and Pinter (2008) and Klijn, Pais, and Vorsat (2010) design small-scale experiments and calculate the ratio of stable or fair results.

outcome between students and one top school, our approach relaxes the requirement on data availability. It is not necessary to know students' complete preference order for all schools. Our empirical strategy is an economical way to evaluate different matching mechanisms. However, this design cannot be used for a modestly ranked school.[14]

In a top school, an increase in the CEE scores of students admitted implies an increase in the welfare of students with high CEE scores. This increase, in turn, implies that ex-post fairness increases; specifically, students who achieved high scores are more likely to be admitted by a most-preferred or top school. Similarly, if college academic performance is a better proxy for the expected CEE scores or academic aptitude of students, an increase in college academic performance of admitted students implies an increase in the welfare of students with a strong academic aptitude, and thus an ex-ante fairer matching result is evident. To the extent that (some forms of) college academic performance may also measure students' preference intensities for that school, an increase in college academic performance of students admitted by this school also implies an increase in ex-ante efficiency.

Therefore, our propositions can be transformed into two testable hypotheses for top schools.

Hypothesis 1: The pre-exam-no-parallel or traditional mechanism should be less likely to assign students with high CEE scores to top schools than the other three mechanisms (i.e. pre-exam-with-parallel, post-score-no-parallel, and post-score-with-parallel mechanisms).

Hypothesis 2: The pre-exam-no-parallel or traditional mechanism can be more likely than the other three mechanisms to assign students with high academic aptitude or high preference intensities to top-ranked schools.

[14] The decline in matching quality for a modest school can stem from the increase in matching quality of a better school because students who were initially matched with the modest school may attend a better school now.

IV. Empirical Model and Data

A. Empirical Model

We exploit policy changes in the admission mechanism, which vary across provinces, to identify the effect of different matching mechanisms on the matching results for top schools. The college admissions of China are administered by the provincial government under national guidelines stipulated by the Ministry of Education. The quota of each university is predetermined and exams are conducted uniformly within each province. Consequently, the admission process for each province is an independent matching problem. The differences in time variations of admission systems across provinces provide an experimental environment for estimating the effects of matching mechanisms on matching quality.

The main challenge lies in the other differences among provinces, including social culture in education, economic development, and demand for education. These differences simultaneously affect the quality of students admitted into top schools and the choice of matching mechanism. To address these concerns, we include provincial fixed-effects to control for time-invariant provincial differences, and year fixed-effects to control for time trends common across all the provinces.

We also control for some time-variant provincial characteristics such as the intensity of admission competition and educational and economic situations in the province. Finally, we control for other related institutional changes that may occur simultaneously or be correlated with changes in the matching mechanisms of the province. After controlling for all these observable differences across provinces and the year fixed-effects, it is reasonable to argue that variations in the changes in matching mechanisms across provinces are exogenous.

The estimation equation is as follows:

$$Y_{ijt} = b_1 * M_{jt} + b_2 * X_{jt} + b_3 * Z_{ijt} + R_j + T_t + \varepsilon_{ijt} \qquad (1)$$

where Y_{ijt} is the measure of the matching quality of student i from province j admitted into the sample school in year t; M_{jt} is a set of institutional variables of the admission system in province j in year t, including the matching mechanism variables; X_{jt} is a set of variables reflecting time-variant provincial characteristics; Z_{ijt} represents the individual characteristics of student i in year t; R_j represents the provincial fixed-effects; and T_t controls for the year fixed-effects.

B. Variables and Measures

This section presents a detailed description of the variables used in the estimation.

Matching quality

We focus on two indicators of matching quality (or student quality) in the sample school: the CEE scores and college academic performance or college GPAs. Compared with the CEE score, college GPA is a better proxy for student academic aptitude and preference intensities in the school/major for three reasons. First, college GPA is less likely to be determined by random shocks because it is an average score across various courses over a long period. Moreover, some measures of college GPA, such as the first-year GPA of Math and English courses, are closely related to the knowledge accumulated in high school. Second, college exams are less likely to depend on rote memorization than the CEE. Third, college study depends more on individual motivation and professional interests.

CEE scores are the main criteria for college admissions in China. However, the scores are not comparable across different years and provinces. What matters in college admissions is the students' ranks on the CEE score within the province in a given year. However, information on students' ranking is unavailable. Three variables are constructed to measure students' ranking. The first one is the ratio of the test score over the full CEE scores, multiplied by 100, which we label as normalized scores. The second variable is the ratio of the difference between the student test score and the eligibility score for admission into first-ranked universities, to the difference between the full score and the eligibility score.[15] The ratio is rescaled by multiplying it by 100. We label this measure “difficulty-adjusted scores” because the eligibility score for admission into first-ranked universities reflects how difficult the exam is for that year. The third variable is whether a student’s CEE score ranks among the top 10 in the province and year that he/she takes the CEE. The first measure eliminates the difference in the scale of CEE scores across provinces and years. The second measure takes into account variations in exam difficulty. Nevertheless, the eligibility score considered in the second measure can be influenced by the matching mechanism. The third measure is a direct but rough measure of a student’s CEE score rank.

College academic performance can be measured in many different ways. The time span of the courses used in calculating GPA is particularly important. We consider GPA for both the first year and the first three years. The first-year GPA is closely related to the knowledge accumulated in high school. The three-year GPA covers more courses and measures student academic aptitude and study interest more broadly. It also smoothes out the maladjustment of students during their first year, which is not unusual in China.

The courses included in calculating GPA are also important. From narrow to broad coverage, we include the following courses: (i) required courses in Math and English, which are highly correlated with high school academic skills and less dependent on the students’ interest in the majors; (ii) courses in (i) and other required core courses; (iii) all required courses, including courses regarded as unimportant for careers, such as politics and sports. This measure is most relevant for assessing scholarship and admission into master programs; and (iv) all courses that a student has taken. GPA is calculated using the following formula: Σ_i $(course\ grade_i * course\ credit_i) / \Sigma_i course\ credit_i$.

[15] During the college admission process, colleges are categorized into different tiers and have different priority to admit students. First-ranked universities are the universities who admit students first.

Policies on College Admissions

For the matching mechanism, we focus on the timing of preference submission and the availability of parallel options. In principle, six different mechanisms exist: (i) preference submission before the exam without parallel options (pre-exam-no-parallel or traditional), (ii) submission before the exam with parallel options (pre-exam-with-parallel), (iii) submission after the exam but before the release of scores without parallel options (post-exam-pre-score-no-parallel), (iv) submission after the exam but before the release of scores with parallel options (post-exam-pre-score-with-parallel), (v) submission after the release of scores without parallel options (post-score-no-parallel), and (vi) submission after the release of scores with parallel options (post-score-with-parallel). In practice, few observations fall under the two mechanisms that have parallel options and ask students to submit preferences before the release of CEE scores (only two provinces, as shown in Table A.2). Estimating the effect of these two mechanisms is highly difficult. Therefore, we exclude all the observations under these two policy regions, leaving four mechanisms for empirical study, namely, the traditional mechanism and the three post-exam mechanisms.

In addition to the change in matching mechanisms, other policy changes related to college admissions are often implemented simultaneously or by turn. Controlling for these policies is necessary to identify the effect of matching mechanisms. Table A.1 illustrates the changes in other related policies.

The first policy change is the reform on the context of the CEE. The objective of the reform is to reduce “rote learning” and send more qualified students to universities. In most provinces, different entrance exams have been used for students from different tracks (humanities versus science and engineering). Prior to 1995, humanities students took six exam subjects (Chinese, Math, English, Politics, History, and Geography) while science students took seven subjects (Chinese, Math, English, Politics, Physics, Chemistry, and

Biology). From 1995 to 2001, most provinces gradually shifted to the “3+2” model or the “traditional CEE.” Under this model, in addition to the three subjects that students from both tracks took (Chinese, Math, and English), humanities students took Politics and History exams while science students took Physics and Chemistry exams. Since 2001, most provinces have shifted to the “3+X” model or the “new CEE.” In this new model, “3” still refers to Chinese, Math, and English while “X” is a single subject that combines all other humanities subjects for humanities students and all other science subjects for science students. Some provinces have adopted other models such as the “3+a comprehensive subject+1 self-chosen subject.” In the regression, we control two binary variables: one for “traditional CEE” and the other for “other CEE,” using “new CEE” as reference.

New high-school curricula have been designed since 2004 to adapt to the new CEE. The central government also decentralized exam administration and exam proposition to the provincial-level governments. We control for the adoption of new curricula and independent provincial exam administration in the regression. Other experiments such as independent admissions by universities and high school recommendation systems have also been tried. These changes are still in the experimental stage and have limited influence on the majority of students; hence, we disregard them in this paper.

Other controls

We control for two sets of time-variant provincial variables. The first set contains variables measuring the intensity of competition in the college admissions for each province-year. It includes the admission quotas of the sample school and that of the sample university, the university popularity measured by the ratio of the eligibility score for the sample university to the eligibility score for first-ranked universities, and finally, the total number of college applicants and the total admission quotas of all colleges.

The second set of variables covers general educational and economic situations in each province and year. It includes the average public expenditures per student in high school, the student–teacher ratio in high school, and the per capita GDP during high school years. Provincial GDP may reflect business cycles that affect the demand for higher education. Public educational expenditures and student–teacher ratios are expected to affect the student quality in high school.

We also control for students' individual characteristics that are unaffected by the matching mechanism, including student's track (humanities vs. science), whether being a minority (vs. Han ethnicity), and dummies indicating the first-year major. Admission quotas for humanities and science students are predetermined separately. CEE subjects and college courses also differ for these two types of students, making it necessary to control for the student's track. Similar arguments motivate the inclusion of minority status and college majors during the first year. Other individual characteristics such as gender, age, and whether the student comes from urban or rural areas are not controlled for because these can be affected by the matching mechanism.[16]

C. Data Source

Data on the students from 1999 to 2009 are provided by the sample school. We exclude students admitted outside the regular admission system, such as students exempted from taking the CEE or students admitted through independent admissions by the university. We obtain a final sample of 1,328 students. Table A.2 shows the descriptive statistics of students in the sample school, indicating that students' average CEE score is high (around 89 out of 100). The proportion of students ranking in the top 10 in their provinces is also high (around 20%). The proportion of humanities students is small (20%). Female students account for more than 50% of the population; only around 14% of the students come from rural areas.

[16] For example, students from urban areas usually have higher CEE scores than those from rural areas. If a shift in the matching mechanism increases the CEE scores of admitted students, such a shift also increases the proportion of students from urban areas. Controlling for an urban dummy tends to result in an underestimation of the effect of this shift on CEE scores.

The information on provincial admission system for each year is collected from various websites. Data on the full CEE scores and eligibility scores for first-ranked universities in each province and year are gathered from the Web (before 2003) and Qiu et al. (various years; after 2003). Other provincial variables are obtained from the China Statistics Yearbook, the Educational Statistics Yearbook of China, and the China Educational Finance Statistics Yearbook (various years).

V. Regression Results

A. CEE Scores

Table 2 provides estimations for the effects of matching mechanisms on the CEE scores of students admitted by the sample school. All regressions include four sets of controls: (i) provincial intensity of admission competition; (ii) provincial economic and educational environment; (iii) individual characteristics of students; and (iv) provincial and yearly fixed effects. All regressions report the robust standard deviations and allow for clustering in each province and each year.

We first use the normalized CEE score as the dependent variable. In column 1, only variables on matching mechanisms are included in the covariates. The result shows that compared with the traditional or pre-exam-no-parallel mechanism (the reference mechanism), all the post-exam mechanisms reflect higher average CEE scores among the students admitted by the top school.[17] Column 2 controls for other CEE institutional variables. The differences in the effects of matching mechanisms on CEE scores decrease, but the changes are very small. More specifically, the average CEE score is 0.93 points (out of 100) higher under the post-exam-pre-score-no-parallel mechanism, 1.3 points higher under the post-score-no-parallel mechanism, and 1.61 points higher under the post-score-with-parallel mechanism. The differences between the three post-exam mechanisms are not significant.

[17] The difference between the traditional mechanism and post-exam-pre-score-no-parallel mechanism is significant only at the 11% level.

In columns 3 and 4, we use the difficulty-adjusted CEE scores as the dependent variable. The findings are similar to those derived from the first two columns. Column 4 shows that, compared with the average difficulty-adjusted CEE score under the traditional mechanism, the average score under the post-exam-pre-score-no-parallel, post-score-no-parallel, and post-score-with-parallel mechanisms increases by 2.93, 3.36, and 4.88 points, respectively.[18] Similar to those observed in the first two columns, the differences between the three post-exam mechanisms are not significant.

Columns 2 and 4 also show the effects of other CEE institutions on the admission quality in terms of CEE scores. For CEE subjects, students admitted under the "3+X" model (the reference) exhibit higher scores than students admitted under the other models.[19] Curriculum reform and independent provincial administration have no significant influence. The effects of other control variables, although not reported because of space limitations, are mostly consistent with our expectations. In particular, a decrease in competitiveness generally reduces the average CEE scores of students. Humanities students have significantly lower scores than science students.

In columns 5 and 6, the dependent variable is a dummy variable indicating whether the admitted student is ranked in the top 10 in his/her province-year. The linear probability model is applied to allow robust standard deviation and clustering in the province and year.[20] Consistent with the results in previous columns, the post-score mechanisms are more likely to match the top 10 students with the sample school than the traditional mechanism. The difference between the post-exam-pre-score-no-parallel mechanism and the traditional

[18] The average difference between the full and eligibility scores for first-ranked universities is roughly 29.25 points. The estimates in column 4 are then equivalent to increases in the normalized score by 0.86 (=29.25*2.93/100), 0.98, and 1.43 points, respectively, which are comparable to those in column 2.

[19] We should be careful with the interpretation of this coefficient. The result may stem from the different relationships between CEE scores and score rankings under different CEE subject systems, and normalization cannot completely eliminate the difference.

[20] We also try the Logit model with fixed effects, which does not allow for robust standard deviations and clustering. The results of the Logit model show that the post-exam-pre-score-no-parallel mechanism is significantly more likely to match top 10 students with the sample school than the traditional mechanism. The results of the remaining mechanisms are similar to those in the LP model.

mechanism is no longer significant; however, it remains significant if we do not consider clustering. These results indicate that the effects of matching mechanisms on top students and mediocre students (still excellent) in this sample school somewhat differ.

In summary, the evidence supports Hypothesis 1: compared with the traditional mechanism, post-exam mechanisms facilitate the admission of students with high CEE scores into top schools.

B. College Academic Performance

Table 3 examines the effects of matching mechanisms on college academic performance. Columns 1 to 4 examine the first-year GPAs of students admitted by the sample school. Results show that students admitted under the post-exam mechanisms do not show higher first-year GPAs than students admitted under the traditional mechanism (reference), although the former students have higher CEE scores as shown in Table 2. The signs of the coefficients indicate that students admitted under the post-exam mechanisms display lower first-year GPAs than students admitted under the traditional mechanism.

The difference is significant for some GPA measures. For example, the average score in Math and English courses under the post-score-no-parallel mechanism is 2.15 points (out of 100) lower than that under the traditional mechanism; this difference is significant at the 5% level. Furthermore, no significant difference is observed between the three post-exam mechanisms. When we include more courses that are less correlated with high school courses in calculating GPAs, such as core courses (column 2), required courses (column 3), and all courses (column 4), the GPAs under the three post-exam mechanisms remain lower than those under the traditional mechanism, although at a smaller magnitude and significance level.

Columns 5 to 8 consider the GPAs for the first three years as the dependent variable. Again, students admitted under the three post-exam mechanisms show worse academic performance than students admitted under the traditional mechanism, although the differences are mostly lower than those in the first-year GPAs and insignificant at the 10% level. The negative effect of the post-score-no-parallel mechanism on the GPA of Math and English courses remains significant.

Given that college GPAs are better measures for academic aptitude or preference intensity than CEE scores, these results are consistent with Hypothesis 2: compared with the post-exam mechanisms, the traditional mechanisms are more likely to assign students with high academic aptitude or high preference intensities to top schools.

However, there is an alternative explanation for our results: students who got low CEE scores (such as students admitted under the traditional mechanism) may study harder than students who got high CEE scores (such as students admitted under the post-exam mechanisms) in college; thus the former students catch up or even perform better than the latter in terms of college GPAs. If students admitted under the tradition mechanism study harder than other students, they would have better performance not only in math and English, but also in other courses, especially courses whose scores are sensitive to efforts, such as major courses. But this prediction is not consistent with our results because Math and English are the courses that students admitted under the traditional mechanism outperform other students most.

Moreover, the GPAs for Math and English courses are closely related to knowledge accumulated in high school; thus, they are more likely than other GPA measures to reflect academic aptitude instead of preference intensity. Because the estimated coefficients of the GPAs for Math and English courses are more negative than the coefficients of the other GPA measures, poor college performance by students admitted under post-exam mechanisms is more likely to result from their weaker academic aptitude than from their lower preference intensity.

The differences between the first-year and three-year GPAs are consistent with the differences between various measures of first-year GAPs. When more courses less related to knowledge accumulated in high school are added, the effects of the matching mechanisms on college GPAs weaken. A potential explanation for this is that, over time, students who have not performed well academically in high school begin to catch up, although on average they perform no better than their counterparts.

We also try different specifications similar to the regressions for the CEE-scores and find that the basic conclusions still hold. For other control variables, students' GPAs under the traditional CEE subjects are significantly lower. Students from provinces with independent administration sometimes obtain higher college GPAs. Other institutional variables and economic variables are mostly insignificant.

C. Correlations between College GPAs and CEE Scores

The previous analyses have shown that, although students admitted under the traditional mechanism have significantly lower CEE scores than those admitted under post-exam mechanisms, their college GPAs are similar or even higher than those of students admitted under post-exam mechanisms. These results are consistent with our hypotheses. However, besides the alternative explanation related to study efforts, another alternative explanation is that CEE scores and college GPAs are uncorrelated, particularly for students admitted by the top school. We directly examine the correlations between CEE scores and college GPAs to test whether the alternative explanation is the main reason for our results.

The first four columns of Table 4 show the regression of college GPAs on CEE scores after controlling for individual characteristics, full CEE scores, and provincial and yearly fixed effects. We use this regression to examine the overall correlation between college GPAs and CEE scores, including the correlation within a matching mechanism and that across different matching mechanisms. The correlation is found to be positive and significant at the

1% level. The first-year GPA for Math and English courses increases by 0.42 points (out of 100) when the normalized CEE score increases by 1 point (out of 100). The correlation becomes smaller but remains significant when more courses are included in the GPAs. The results continue to hold when we control for other provincial institutional and economic variables.

In columns 5 to 8 of Table 4, we include interaction terms between the CEE scores and the matching mechanisms. We find that the correlation within a mechanism does not significantly differ across mechanisms. One exception is that the correlation becomes insignificant under the post-score-with-parallel mechanism.

These results indicate that, within a given mechanism, college GPAs and CEE scores are significantly correlated, which contradicts the alternative explanation that CEE scores and college GPAs are uncorrelated. Therefore, the difference between the effects of matching mechanisms on college GPAs and those on CEE scores can only be explained by the weak (or even negative) cross-mechanism correlation between college GPAs and CEE scores. This explanation is consistent with our hypotheses.

D. Sensitivity Analyses and Other Effects

We conduct three sensitivity tests to (i) distinguish between humanities and science students, (ii) to run a medium regression, and (iii) to examine the effect of matching mechanisms on other characteristics of students.

The CEE system of China treats humanities and science students differently; specifically, their exam subjects and admission quotas are different. Although reforms on the admission system are implemented simultaneously for humanities and science students, the effects of these reforms can be different. Humanities and science students may also have different preferences for the sample school because the sample school is mainly famous for its science and engineering programs. These differences may not be fully controlled by introducing a dummy variable for humanities students. Therefore, we exclude all humanities students in the regression as a robustness test. Minorities are also excluded for similar reasons. Table 5 shows results similar to those in Tables 3 and 4, although the significance declines as the number of observations decreases.

Since a few students may have much higher or lower CEE scores or college GPAs than others, we conduct a medium regression to avoid the influence of the outliers.[21] The results are shown in Table 6. Our basic conclusions still hold, and the negative effects of three post-exam mechanisms on college GPAs become more significant.

Finally, we find that matching mechanisms matter for other characteristics of students admitted by the top school. Table 7 shows that the current reforms targeting the post-score-with-parallel mechanism favor females and younger students. More specifically, column 1 of Table 7 uses a dummy variable for female students as the dependent variable. The coefficients of the three post-exam mechanisms are all positive, with the coefficient of the post-score-with-parallel mechanism significant at the 5% level. The dependent variable in column 2 is a dummy variable indicating whether a student is less than 17 years old in the first year of college. The coefficients of the three post-exam mechanisms are all positive, and two are significant at the 10% level. The result is consistent with that in column 3, where the dependent variable is whether a student being more than 19 years old in the first year of college. The last two columns show that matching mechanisms do not affect students' residence status (urban or rural) and whether student having taken the CEE more than once.

Our findings on female students are consistent with the explanation that female students are more risk-averse than male students and are more likely to apply to top schools under the post-exam mechanisms in which the uncertainty on test scores mostly disappears. A similar explanation may be applied to younger students who have larger variations in CEE scores.

[21] We implement the within-group fixed-effect model to address the degree-of-freedom problem.

These issues warrant further research.

VI. Conclusion

This paper uses real-world data to test the hypotheses related to how college matching mechanisms affect the quality of students admitted by a premier school. The theoretical predictions are drawn from the general theory in school choice literature and our own examples. The empirical analyses exploit the natural experiment arising from provincial and time variations in matching mechanisms.

The results show that, compared with the traditional or pre-exam-no-parallel mechanism, post-exam mechanisms (with/without parallel options) are more likely to match top schools with students who have high CEE scores. However, high CEE scores do not automatically translate into better college academic performance. Our results actually show the opposite. If college academic performance is a better indicator of academic aptitude (or interest in the school), then the traditional mechanism is a better option for top schools if they prefer students with high academic aptitude (or strong preference intensities). These findings imply that the traditional mechanism is ex-ante fairer (or more efficient) than the post-exam mechanisms. The results also imply that students are not truth-telling under the traditional mechanism. Otherwise the matching outcome should be the same as the other three, of which two are truth-telling.

Our results provide real-world evidence supporting the argument that the BOS mechanism may be better than the TTC or SD mechanism from the ex-ante point of view. In particular, a mechanism with more uncertainty regarding the priority order of schools on students, such as a mechanism with preference submission prior to the exam, may increase social welfare by compelling students to choose schools based on their CEE score expectations, which strongly depends on their academic aptitude or preference intensity for the school. Moreover, the difference between high CEE scores and high academic aptitude (or interest) implies that mechanisms more strongly emphasizing one-shot CEE scores, such as the mechanisms with parallel options, can be less ex-ante fair (or efficient). Since students can be strategic under an ex-ante fairer or ex-ante more efficient mechanism, this also implies that strategy-proof may not always be a desirable property for matching mechanisms.

The reforms on matching mechanisms in China lean toward mechanisms that try to reduce uncertainty and preference manipulation and emphasize exam scores more. Our findings call for a reconsideration of the current reform trend, an argument that echoes the challenges raised by many students. Hou et al. (2009) conduct a survey of college students in Shanghai and finds that introducing parallel options is favored by only slightly more than half of the students. Many students think the policy protects students with high CEE scores more than students with high academic aptitude. Furthermore, fewer than half of the students favor preference submission after the release of scores. Other criticisms on the reform include scores becoming the only standard for admission and the tendency of the reform to drive students toward placing excessive importance on university ranking, but little on their own professional interests (Yang, 2009).

There are several caveats to interpreting our results. First, we restrict our investigation to top-ranked schools. The findings cannot be directly generalized to other types of schools. In addition, the explanations of the results are based on the assumption that all students strategically report their preference, yet some students may not be perfectly rational in real life. Also, students' risk attitudes should play roles in the matching outcomes and social welfare. All these issues warrant further research.

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TABLE 1
PROVINCIAL DIFFERENCES IN COLLEGE MATCHING MECHANISMS

	Part A: Distribution of College Matching Mechanisms over the Years				
	Timing of Preference Submission			Total Number of Provinces	Number of Provinces with Parallel Options
Year	Before the CEE	After the Exam but Before the Release of CEE Scores	After the Release of CEE Scores		
1999	5	18	5	28	0
2000	6	17	5	28	0
2001	7	16	5	28	0
2002	6	17	6	29	0
2003	3	18	10	31	1
2004	5	14	12	31	1
2005	5	11	15	31	2
2006	4	11	16	31	2
2007	4	9	18	31	4
2008	2	7	22	31	7
2009	2	6	23	31	17
Total	49	144	137	330	34

	Part B: Distribution of Students over Different Mechanisms			
	Submission Before the Exam	Submission After the Exam But Before the Release of Scores	Submission After the Release of Scores	Total
No parallel options	329	399	441	1169
With parallel options	14	9	159	182
Total	343	408	600	1351

Note: Information from some provinces is missing in some years.

TABLE 2
EFFECTS OF MATCHING MECHANISMS ON CEE SCORES FOR THE TOP SCHOOL

Dependent Variables:	Normalized CEE Scores		Difficulty-adjusted CEE Scores		Top 10 in the Province-year	
	(1)	(2)	(3)	(4)	(5)	(6)
Post-exam-pre-score-no-parallel	1.292	0.926	3.891**	2.928	0.010	0.001
	(0.797)	(0.728)	(1.933)	(1.868)	(0.056)	(0.059)
Post-score-no-parallel	1.469**	1.303**	3.842**	3.358**	0.172***	0.166***
	(0.638)	(0.609)	(1.643)	(1.688)	(0.044)	(0.046)
Post-score-with-parallel	1.976**	1.607**	5.768***	4.875**	0.288***	0.283***
	(0.830)	(0.750)	(2.184)	(2.100)	(0.071)	(0.073)
Traditional CEE		1.713**		3.590*		0.007
		(0.823)		(2.104)		(0.051)
Other CEE		1.646**		4.691**		0.076
		(0.809)		(2.296)		(0.064)
New high school curricula		-0.207		-0.881		-0.041
		(0.526)		(1.438)		(0.057)
Provincial administration		0.626		1.021		-0.043
		(0.584)		(1.494)		(0.050)
P value: post-exam-pre-score-no-parallel = post-score-no-parallel	0.725	0.444	0.970	0.739	0.00176	0.00191
P value: post-score-no-parallel = post-score-with-parallel	0.331	0.515	0.195	0.261	0.0501	0.0521
Obs.	1,327	1,327	1,327	1,327	1,328	1,328
R^2	0.509	0.528	0.574	0.586	0.290	0.292
Group numbers	30	30	30	30	30	30

Note: Robust standard errors are shown in parentheses, allowing for clustering in each province and each year. ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively. All regressions control for provincial and yearly fixed-effects and provincial characteristics, including admission quotas of the sample school, admission quotas and popularity of the sample university, number of college applicants, total admission quotas in the province, full CEE scores, log (education spending), student–teacher ratio, and log (per capita GDP). Characteristics of students are also controlled for, including whether in the track of humanities, being a minority, and dummies for majors in the first college year.

TABLE 3
EFFECTS OF MATCHING MECHANISMS ON COLLEGE GPAS FOR THE TOP SCHOOL

Dependent Variables:	First-year GPAs				Three-year GPAs			
	Math, English	Core Courses	Required Courses	All Courses	Math, English	Core Courses	Required Courses	All Courses
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post-exam-pre-score-no-parallel	-1.238	-0.785	-0.512	-0.383	-1.322	-0.289	-0.111	-0.075
	(1.141)	(0.881)	(0.591)	(0.561)	(1.036)	(0.778)	(0.587)	(0.553)
Post-score-no-parallel	-2.149**	-1.289*	-0.774*	-0.709	-1.842**	-0.716	-0.549	-0.501
	(0.895)	(0.681)	(0.456)	(0.436)	(0.835)	(0.620)	(0.450)	(0.416)
Post-score-with-parallel	-1.322	-0.640	-0.317	-0.305	-1.053	-0.083	-0.125	-0.110
	(1.174)	(0.928)	(0.636)	(0.593)	(1.286)	(1.003)	(0.749)	(0.703)
Traditional CEE	-1.748*	-1.656**	-1.355***	-1.063**	-1.509	-1.335**	-1.291**	-1.236**
	(0.919)	(0.693)	(0.484)	(0.458)	(1.003)	(0.664)	(0.529)	(0.507)
Other CEE	-1.274	-1.065	-0.589	-0.438	-1.099	-0.573	-0.382	-0.369
	(0.966)	(0.777)	(0.520)	(0.485)	(0.902)	(0.711)	(0.539)	(0.503)
New high school curricula	-0.749	-0.623	-0.411	-0.405	-0.740	-0.512	-0.491	-0.498
	(0.948)	(0.761)	(0.501)	(0.453)	(0.947)	(0.722)	(0.551)	(0.511)
Provincial administration	1.873**	1.055	0.701	0.576	1.112	0.595	0.537	0.482
	(0.900)	(0.729)	(0.494)	(0.451)	(0.961)	(0.801)	(0.621)	(0.576)
P value: post-exam-pre-score-no-Parallel = post-score-no-parallel	0.296	0.468	0.567	0.444	0.519	0.509	0.378	0.358
P value: post-score-no-parallel = post-score-with-parallel	0.358	0.372	0.342	0.350	0.432	0.472	0.526	0.532
Obs.	1,325	1,325	1,325	1,325	1,184	1,184	1,184	1,184
R^2	0.135	0.145	0.193	0.212	0.146	0.153	0.187	0.195
Group numbers	30	30	30	30	30	30	30	30

Note: Robust standard errors are shown in parentheses, allowing for clustering in each province and each year. ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively. All regressions control for provincial and yearly fixed-effects and provincial characteristics, including admission quotas of the sample school, admission quotas and popularity of the sample university, number of college applicants, total admission quotas in the province, full CEE scores, log (education spending), student–teacher ratio, and log (per capita GDP). Characteristics of students are also controlled for, including whether in the track of humanities, being a minority, and dummies for majors in the first college year.

TABLE 4
CORRELATION BETWEEN COLLEGE GPAS AND CEE SCORES

Dependent Variables:	First-year GPAs		Three-year GPAs		First-year GPAs		Three-year GPAs	
	Math, English	Required Courses	Math, English	Required Courses	Math, English	Required Courses	Math, English	Required Courses
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Normalized CEE score	0.419***	0.273***	0.403***	0.260***	0.501***	0.284***	0.419***	0.248***
	(0.094)	(0.050)	(0.090)	(0.051)	(0.180)	(0.090)	(0.154)	(0.084)
CEE score * post-exam-pre-score-no-parallel					-0.052	0.036	-0.025	0.037
					(0.214)	(0.112)	(0.187)	(0.112)
CEE score * post-score-no-parallel					0.068	0.061	0.083	0.049
					(0.219)	(0.113)	(0.190)	(0.116)
CEE score * post-score-with-parallel					-0.636***	-0.251**	-0.314	-0.113
					(0.238)	(0.123)	(0.264)	(0.153)
Post-exam-pre-score-no-parallel					3.669	-3.829	0.844	-3.513
					(18.897)	(10.005)	(16.580)	(9.948)
Post-score-no-parallel					-7.605	-6.359	-9.141	-5.076
					(19.205)	(9.988)	(16.771)	(10.312)
Post-score-with-parallel					55.713***	21.579**	26.844	9.506
					(21.119)	(10.899)	(23.503)	(13.618)
Obs.	1,324	1,324	1,183	1,183	1,324	1,324	1,183	1,183
R^2	0.114	0.186	0.139	0.178	0.124	0.195	0.145	0.181
Groups	30	30	30	30	30	30	30	30

Note: Robust standard errors are shown in parentheses, allowing for clustering in each province and each year. ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively. All regressions control for provincial and yearly fixed-effects, full CEE scores, dummies for majors in the first college year, and student demographics, including minority status and whether in the track of humanities.

TABLE 5
EFFECTS OF MATCHING MECHANISMS ON CEE SCORES AND COLLEGE GPAS FOR THE TOP SCHOOL: NON-MINORITY SCIENCE STUDENTS

Dependent Variables:	Normalized CEE Scores	Difficulty-adjusted CEE Scores	Top 10 in the Province-year	First-year GPAs		Three-year GPAs	
				Math, English	Required Courses	Math, English	Required Courses
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Post-exam-pre-score-no-parallel	0.851	2.471	0.009	-0.142	-0.215	-0.017	0.233
	(0.744)	(1.890)	(0.062)	(1.035)	(0.586)	(0.988)	(0.561)
Post-score-no-parallel	1.697***	3.916**	0.154***	-1.305	-0.610	-0.962	-0.283
	(0.634)	(1.688)	(0.045)	(0.873)	(0.472)	(0.850)	(0.450)
Post-score-with-parallel	2.570***	7.383***	0.328***	-0.423	-0.100	0.130	0.655
	(0.856)	(2.308)	(0.067)	(1.391)	(0.765)	(1.334)	(0.813)
Traditional CEE	2.214***	4.833**	0.015	0.640	-0.249	0.621	0.006
	(0.767)	(2.018)	(0.048)	(1.069)	(0.569)	(1.078)	(0.538)
Other CEE	1.468*	3.774*	0.055	-0.710	-0.220	-0.932	0.027
	(0.759)	(2.072)	(0.057)	(1.062)	(0.535)	(0.891)	(0.531)
New high school curricula	-0.449	-1.894	-0.127**	-0.923	-0.653	-1.166	-0.903
	(0.598)	(1.672)	(0.059)	(1.173)	(0.621)	(1.056)	(0.650)
Provincial administration	0.056	0.557	-0.034	0.999	0.379	0.395	0.257
	(0.601)	(1.626)	(0.057)	(0.930)	(0.512)	(0.947)	(0.636)
P value: post-exam-pre-score-no-Parallel = post-score-no-parallel	0.126	0.321	0.0171	0.185	0.419	0.269	0.330
P value: post-score-no-parallel = post-score-with-parallel	0.126	0.0368	0.00523	0.385	0.379	0.274	0.165
Obs.	991	991	992	990	990	912	912
R^2	0.488	0.394	0.259	0.143	0.178	0.126	0.166
Groups	30	30	30	30	30	30	30

Note: Robust standard errors are shown in parentheses, allowing for clustering in each province and each year. ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively. All regressions control for provincial and yearly fixed-effects and provincial characteristics, including admission quotas of the school, admission quotas and popularity of the university, number of college applicants, total admission quotas in the province, full CEE scores, log (education spending), student–teacher ratio, and log (per capita GDP). Characteristics of students are also controlled for, including whether in the track of humanities, being a minority, and dummies for majors in the first college year.

TABLE 6
EFFECTS OF MATCHING MECHANISMS ON CEE SCORES AND COLLEGE GPAS FOR THE TOP SCHOOL: MEDIAN REGRESSION

Dependent Variables	Normalized CEE Scores	Difficulty-adjusted CEE Scores	First-year GPAs		Three-year GPAs	
			Math, English	Required Courses	Math, English	Required Courses
	(1)	(2)	(3)	(4)	(5)	(6)
Post-exam-pre-score-no-parallel	0.851**	2.608*	-2.877	-1.168	-1.740	-0.842
	(0.432)	(1.496)	(1.897)	(0.867)	(1.520)	(1.073)
Post-score-no-parallel	1.293***	2.764**	-3.393**	-0.782	-1.694	-0.722
	(0.355)	(1.234)	(1.570)	(0.719)	(1.259)	(0.885)
Post-score-with-parallel	1.527***	4.171**	-2.212	0.153	-0.827	0.412
	(0.471)	(1.632)	(2.069)	(0.945)	(1.785)	(1.270)
Traditional CEE	1.596***	2.767**	-3.222*	-2.485***	-2.014	-2.049**
	(0.396)	(1.382)	(1.737)	(0.794)	(1.362)	(0.956)
Other CEE	1.546***	3.907***	-2.067	-0.665	-1.562	-0.115
	(0.403)	(1.423)	(1.783)	(0.813)	(1.446)	(1.024)
New high school curricula	0.003	-1.171	-1.070	-0.308	-1.249	-0.827
	(0.334)	(1.165)	(1.473)	(0.678)	(1.199)	(0.848)
Provincial administration	0.851**	2.608*	-2.877	-1.168	-1.740	-0.842
	(0.432)	(1.496)	(1.897)	(0.867)	(1.520)	(1.073)
P value: post-exam-pre-score-no-parallel = post-score-no-parallel	0.166	0.890	0.718	0.551	0.968	0.885
P value: post-score-no-parallel = post-score-with-parallel	0.497	0.239	0.436	0.174	0.537	0.256
Obs.	1,327	1,327	1,325	1,325	1,184	1,184

Note: Robust standard errors are shown in parentheses, allowing for clustering in each province and each year. ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively. All regressions control for provincial and yearly fixed-effects and provincial characteristics, including admission quotas of the school, admission quotas and popularity of the university, number of college applicants, total admission quotas in the province, full CEE scores, log (education spending), student–teacher ratio, and log (per capita GDP). Characteristics of students are also controlled for, including whether in the track of humanities, being a minority, and dummies for majors in the first college year.

TABLE 7
EFFECTS OF MATCHING MECHANISMS ON THE DEMOGRAPHIC DISTRIBUTION OF THE STUDENTS ADMITTED BY THE TOP SCHOOL: LINEAR PROBABILITY MODEL

Dependent Variables	Female Student	Age≤17	Age≥19	Urban Student	Non-repeating Student
	(1)	(2)	(3)	(4)	(5)
Post-exam-pre-score-no-parallel	0.080	0.112*	-0.032	0.020	-0.025
	(0.072)	(0.060)	(0.060)	(0.040)	(0.048)
Post-score-no-parallel	0.096	0.069	-0.026	0.007	0.012
	(0.059)	(0.043)	(0.052)	(0.034)	(0.036)
Post-score-with-parallel	0.172**	0.124**	-0.111*	0.032	0.070
	(0.071)	(0.059)	(0.062)	(0.057)	(0.045)
Traditional CEE	-0.005	0.042	0.041	-0.014	0.041
	(0.055)	(0.046)	(0.049)	(0.043)	(0.033)
Other CEE	-0.029	0.022	0.004	0.098*	0.044
	(0.070)	(0.059)	(0.056)	(0.055)	(0.043)
New high school curricula	-0.018	-0.055	-0.015	0.086**	0.040
	(0.057)	(0.044)	(0.045)	(0.040)	(0.036)
Provincial administration	0.062	0.064	-0.083*	0.007	0.009
	(0.065)	(0.053)	(0.046)	(0.040)	(0.036)
P value: post-exam-pre-score-no-parallel = post-score-no-parallel	0.775	0.382	0.880	0.751	0.376
P value: post-score-no-parallel = post-score-with-parallel	0.175	0.285	0.0421	0.626	0.0670
Obs.	1,328	1,328	1,328	1,328	1,328
R^2	0.059	0.027	0.034	0.034	0.035
Group Number	30	30	30	30	30

Note: Robust standard errors are shown in parentheses, allowing for clustering in each province and each year. ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively. All regressions control for provincial and yearly fixed-effects and provincial characteristics, including admission quotas of the school, admission quotas and popularity of the university, number of college applicants, total admission quotas in the province, full CEE scores, log (education spending), student–teacher ratio, and log (per capita GDP). Characteristics of students are also controlled for, including whether in the track of humanities, being a minority, and dummies for majors in the first college year.

Appendix

TABLE A.1
DISTRIBUTION OF OTHER POLICIES ON CEE

	CEE Context			High School Curriculum		Independent Administration in the Province	
Year	3+X	3+2 (Traditional CEE)	Other CEE	Traditional	New	Independent	National
1999	0	29	2	31	0	1	30
2000	4	25	2	31	0	1	30
2001	15	13	3	31	0	1	30
2002	26	0	5	31	0	1	30
2003	25	0	6	31	0	1	30
2004	26	0	5	27	4	4	27
2005	27	0	4	26	5	5	26
2006	28	0	3	20	11	8	23
2007	26	0	5	15	16	8	23
2008	26	0	5	11	20	8	23
2009	25	0	6	7	24	11	23
Total	228	67	46	261	80	49	292

TABLE A.2
DESCRIPTIVE STATISTICS

Variables	Observation	Mean	S.D.	Max	Min
Normalized CEE scores	1327	89.0	3.9	74.7	110.0
Difficulty-adjusted CEE scores	1327	62.1	12.4	25.3	134.7
Top 10 in the province	1328	0.2	0.4	0	1
GPA for compulsory Math and English courses in the first year	1325	80.8	8.8	59.0	99.7
GPA for core courses in the first year	1325	81.5	6.9	60.1	96.7
GPA for compulsory courses in the first year	1325	83.0	4.8	68.0	94.4
GPA for all courses in the first year	1325	83.4	4.5	68.8	94.3
GPA for compulsory Math and English courses in three years	1325	81.1	7.7	59.3	99.0
GPA for core courses in three years	1325	82.9	6.0	61.0	95.5
GPA for compulsory courses in three years	1325	83.7	4.5	68.1	93.7
GPA for all courses in three years	1325	84.0	4.3	68.7	93.6
Sample school admission quotas in each province	1328	6.7	8.1	0.0	33.0
Sample university admission quotas in each province	1328	95.6	107.9	0.0	342
Popularity of the sample university	1328	122.1	7.0	102.3	158.3
Number of college applicants in each province (thousand)	1328	286.1	199.7	23.7	1151.8
Total quotas of colleges in each province (thousand)	1328	179.7	99.1	9.1	519.2
Humanities students	1328	0.20	0.40	0	1
Minority students	1328	0.07	0.26	0	1
Female students	1328	0.57	0.50	0	1
Age≤17	1328	0.22	0.42	0	1
Age≥19	1328	0.19	0.39	0	1
Non-repeating students	1328	0.91	0.29	0	1
Urban students	1328	0.86	0.35	0	1

Note: Student's normalized CEE score=student's CEE score/full score*100. Student's difficulty-adjusted CEE score = (student's CEE score – eligibility score of first-ranked universities)/(full CEE score–eligibility score of first-ranked universities)*100. Popularity of sample university = Eligibility score of the sample university/eligibility score of first-ranked universities. The difference in the number of observations is caused by the exit of three students from the sample school, and information on the CEE score is missing for one student.

Appendix A. Acyclicity

Ergin (2002) is the first paper introducing the concept of acyclicity (later called Ergin-acyclicity). He observed the tradeoff of stability/fairness and efficiency among different school choice mechanisms, and then asked when (if possible) a stable mechanism (e.g., Gale-Shapley/Deferred Acceptance mechanism) might be also efficient, or vice versa, when an efficient mechanism (e.g., Top trading cycles mechanism) might also be stable (adaptive to a priority structure, in his words) under some conditions.

A further question would be: "Why TTC (or DA) mechanism can result in non-stable (or non-efficient) matching outcomes?" Consider for example the TTC mechanism. It proceeds by asking students who have first priority of (or "own") specific schools to explore among themselves mutual exchange opportunity of schools they own. The procedure guarantees the final outcome being efficiency. However, it may result in unstable matching when schools have somehow heterogeneous priority orders among students. Imagine, for example, that two students are at the same priority order in two different schools and had been admitted respectively by these two schools. Then they trade with each other because they prefer each other's school (this is always possible for some preference orders among students), the outcome may be unstable because the trade somehow "damages" the priority order originally set up by TTC mechanism, which initially assign students to schools of which they have the highest priority. In other words, students who get into one school by "selling" schools they have priority might steal other students' priority in the school he "buys". (For more concrete example, see Ergin, 2002, pp.2490-2491).

It turns out that if we can prevent some form of heterogeneity among schools' priority, we can illuminate those unstable results even if we allow mutual exchange. This homogeneity of priority structure is defined as acyclicity.

Definition A.1 (Ergin-acyclicity). Let $\succcurlyeq$ be a priority structure and q a vector of quotas. A *cycle* is constituted of distinct schools a, $b \in A$ and students i, j, $k \in N$ such that the following are satisfied:

(C) Cycle condition: $i \succ_a j \succ_a k \succ_b i$.

(S) Scarcity condition: There exist (possibly empty) disjoint sets of agents N_a, $N_b \subset N \backslash \{i, j, k\}$ such that $N_a \subset U_a(j)$, $N_b \subset U_b(i)$, $|N_a| = q_a - 1$ and $|N_b| = q_b - 1$.

A priority structure is *(Ergin-) acyclic* if it has no such cycles.

In the definition, A is the set of schools and N the set of students. $U_a(i) = \{j \in N | j \succ_a i\}$ is a set of students who have higher priority in school a than student i. $j \succ_a i$ is defined as the case where $j \succcurlyeq_a i$ and not $i \succcurlyeq_a j$.

The cycle condition (C) is at the heart of this definition. It prevents different schools from ranking students in different way such that a cycle of priority order among schools exists. (It is obvious that within any single school, such cycle is prevented because of rationality.) The scarcity condition requires that quotas are limited such that students would compete for admission in different schools.

Ergin (2002) proved that, if Ergin-acyclicity of priority structure is satisfied, Gale-Shapley mechanism is also efficient (besides stable). Yet he did not answer when TTC mechanism is stable (besides efficient). This is done by Kesten (2006), by introducing a variant of acyclicity (later called Kesten-acyclicity) as the following:

Definition A.2 (Kesten-acyclicity). Let $\succcurlyeq$ be a priority structure and q a vector of quotas. A *cycle* is constituted of distinct schools a, $b \in A$ and students i, j, $k \in N$ such that the following are satisfied:

(C) Cycle condition: $i \succ_a j \succ_a k$ and $k \succ_b i, j$.

(S) Scarcity condition: There exist (possibly empty) disjoint sets of agents $N_a \subset N\backslash\{i, j, k\}$ such that $N_a \subset U_a(i) \cup (U_a(j) \backslash U_b(k))$, and $|N_a| = q_a - 1$.

A priority structure is *(Kesten-) acyclic* if it has no such cycles.

It can be proved that Kesten-acyclicity implies Ergin-acyclicity (Kesten, 2006, Lemma 1). Kesten (2006) proved that TTC is stable (and equal to DA) when Kesten-acyclicity is satisfied.

Finally, Haeringer and Klijn (2009) introduce yet other two variants of acyclicity as the following:

Definition A.3 (X-acyclicity). Let $\succcurlyeq$ be a priority structure and q a vector of quotas. A *cycle* is constituted of distinct schools a, $b \in A$ and students i, $j \in N$ such that the following are satisfied:

(C) Cycle condition: $i \succ_a j$ and $j \succ_b i$.

(S) Scarcity condition: There exist (possibly empty) disjoint sets of agents $N_a \subseteq N\backslash\{i\}$, $N_b \subseteq N\backslash\{j\}$ such that $N_a \subseteq U_a(i)$, $N_b \subseteq U_b(j)$, $|N_a| = q_a - 1$ and $|N_b| = q_b - 1$.

A priority structure is *(X-) acyclic* if it has no such cycles.

X-acyclicity means that "two schools cannot prioritize differently two students that compete for the last available set in both schools" (Haeringer and Flijn, 2009, pp.1924).

Definition A.4 (Strongly X-acyclicity). Let $\succcurlyeq$ be a priority structure and q a vector of quotas. A *weak cycle* is constituted of distinct schools a, $b \in A$ and students i, $j \in N$ such that the following are satisfied:

(C) Cycle condition: $i \succ_a j$ and $j \succ_b i$.

(S) Scarcity condition: There exist (possibly empty) disjoint sets of agents $N_a \subseteq N \backslash \{i\}$, $N_b \subseteq N \backslash \{j\}$ such that $N_a \subseteq U_a(j)$, $N_b \subseteq U_b(i)$, $|N_a| = q_a - 1$ and $|N_b| = q_b - 1$.

A priority structure is *(strongly X-) acyclic* if it has no such cycles.

The only difference of definition A.4 from A.3 is that in the scarcity condition the requirement $N_a \subseteq U_a(i)$, $N_b \subseteq U_b(j)$ are relaxed to $N_a \subseteq U_a(j)$, $N_b \subseteq U_b(i)$. It can be easily shown that strongly X-acyclicity implies X-acyclicity.

Haeringer and Flijn (2009) proved that under strong X-acyclicity, both Boston mechanism and DA mechanism implement efficient matching in *any* of its Nash equilibrium, and the stable matching is unique. It also shows that under Kesten- and X-acyclicity, TTC implements stable and efficient matching in *any* of its Nash equilibrium (not only in the truth-telling equilibrium).

The basic lesson thus is: under some acyclic conditions, all mechanisms (BOS, DA and TTC) tend to converge to the same (and even unique) matching which is both efficient and stable/fair. Yet BOS mechanism is still not strategy-proof.

In China's college admission system, since all the schools determine their priority order on students based solely on their CEE scores, all the schools have the exactly same priority orders of student. That is, for any two students i, j and any two schools a, b, $i \succ_a j$ implies $i \succ_b j$. It is easy to see that if all the schools have the same priority orders on students, all the acyclic conditions mentioned above are satisfied: No cycle conditions (C) of all the four definition (A.1 to A.4) can be satisfied. We can state it as a formal conclusion.

Lemma A.1 (acyclicity). If all the schools have the same priority order on all the *students, the priority structure satisfied all the above four (Ergin-, Kesten-, X- and Strongly X-) acyclic conditions.*

Appendix B. Proof of Proposition 1

To see whether a mechanism is ex-post efficient/fair, we ask for any realization of CEE score distributions, the mechanism leads to efficient/fair matching outcomes, for any students' preference order (definition 1.1, 2.1).

Under those two mechanisms, when students submit their preference, their CEE scores are realized and known by all the schools and students. From our description of those two mechanisms in the previous section, it's easy to say that, for any realization of CEE scores, post-score-with-parallel mechanism is equivalent to TTC/SD mechanism, and post-score-no-parallel mechanism is equivalent to BOS mechanism. Note also that in any of these two mechanisms, schools' priority order is solely determined by realized test scores, thus satisfying the acyclic property (Appendix A, lemma A.1).

According to Abdulkadiroglu and Sonmez (2003), proposition 3 and 4, for any priority order of schools, TTC mechanism is efficient and strategy-proof. And according to Kesten (2006), theorem 1, TTC is also efficient for acyclic priority order of schools. Those results implies in truth telling equilibrium, the post-score-with-parallel mechanism implements ex-post efficient and fair matching. Further with Haeringer and Klijn (2009), where they state that under (somehow stronger) acyclic property, TTC implement unique efficient and fair matching in *any* NE (Theorem 6.4, 7.2, 7.3). We conclude that post-score-with-parallel mechanism is ex-post efficient and fair, and also strategy-proof, with a unique matching in any NE.

According to Abdulkadiroglu and Sonmez (2003), and also it would be very easy to show that, BOS mechanism is not strategy-proof. According to Ergin and Sonmez (2006), theorem 1, however, the Nash equilibrium outcome under BOS mechanism is fair. And according to Haeringer and Klijn (2009), theorem 7.3, the Nash equilibrium outcome under BOS mechanism is efficient and fair, and also unique, when acyclic property is satisfied. So the post-score-no-parallel mechanism implements (uniquely) ex-post efficient and fair matching in NE. But it is not strategy-proof. ■

Appendix C. Proof of Proposition 2

We first note that the pre-exam-with-parallel mechanism is the same as the TTC/SD mechanism, except that when students submit their preferences, their test scores are not realized. This leads to uncertainty on schools' priority order on students when students submit their preference order. Abdulkadiroglu and Sonmez (2003, proposition 4)) has proved that canonical TTC/SD mechanism is strategy-proof. That is, truth telling is a weakly dominant strategy for any student. It can be shown that, as in the canonical TTC/SD mechanism, here truth telling is still a dominant strategy.[22]

Given that truth telling strategy is played, the result for post-score-with-parallel mechanism, or just TTC/SD mechanism, can be carried over to the pre-exam-no-parallel exam. ■

Appendix D. Equilibrium of Example 1

Formally, we prove the following proposition:

Proposition A.1. Example 1 has a unique pure-strategy Nash equilibrium outcome: Student A must go to school 1, student B go to school 2 when he/she has a higher score than student 3 (with probability of 21/27); otherwise he/she will go to school 3. Student C will go to the school left correspondingly. This outcome is supported by the following combination of strategies (where x_i, y_i, z_i represent arbitrary schools.)

[22] More formally, denote G(R) as a game played by students under the TTC/SD mechanism when the test score is realized as a vector R. Since truth telling is dominant strategy for any R, so for any player i, $\pi(P_i, S_{-i}) \geq \pi(S_i, S_{-i})$ for R and any S_{-i}, and $S_i \neq P_i$, where Pi is a truth telling strategy. Then for a game when R is not realized, playing Pi is still a dominant strategy since $\pi(P_i, S_{-i}) \geq \pi(S_i, S_{-i})$ implies $E\,\pi(P_i, S_{-i}) \geq E\,\pi(S_i, S_{-i})$, where expectation is taken on all the possible realization of R.

Student A: （$1, x_1, x_2$）

Student B：（$2, y_1, y_2$）

Student C：（$2, z_1, z_2$）

Proof. Consider the first choice of three students. Note that in equilibrium all of them must go to one of the three schools. For student A, choosing school 1 will bring him an expected payoff no less than 100*（6/27+15/27）+25*（1-6/27-15/27）=83>74=67*（21/27）+100*（6/27）, the latter is his highest possible payoff when he puts any other school into his first choice. So student A must choose school 1 as his first choice.

Given that student A chooses school 1 as his first choice, consider student B. If she chooses school 1 as her first choice, then under the equilibrium, student C must choose school 2 as his first choice. Student B can only go to school 1 when her score is higher than student A's, and school 3 otherwise. Her expected payoff is: 100*(6/27) +25*(1-6/27) =42. But when she chooses school 2 as her first choice, she can go to school 2 when she has a higher score than student C, which gives her an expected payoff no less than: 67*(15/27+6/27)+25*(1-15/27-6/27)=58>42. So student B must put school 2 into her first choice.

Given the first choice of student A and B, student C must choose school 2 as his first choice.

Given first choices of all the three students, student A must go to school 1, student B must go to school 2 or 3, depending on her relative score to student C. Student C goes to the school left correspondingly. Any choices in their second or third wills will not affect the matching result, so those choices can be arbitrary. ■

Appendix E. Equilibrium of Example 2

Formally, we prove the following proposition:

Proposition A.2. Example 2 has a unique pure-strategy Nash equilibrium outcome: Student A and B will go to school 1 or 3 with equal probability. Student C will definitely go to school 2. The result is supported by the following combination of strategies (where x_i, y_i, z_i represent arbitrary schools.)

Student A：(1, 2, 3)

Student B：(1 ,2, 3)

Student C：(2 ,x_1, x_2)

Proof. Consider the first choice of student A. Choosing school 1 as his first choice will lead to an expected payoff no less than 100*(1/3)+25*(2/3)=50. If he chooses school 2 as his first choice, then under equilibrium, at least one of the other two students will choose school 1 as his first choice, student A will lose all the chance of going to school 1. In that case student A' s largest payoff can only come from going to school 2, which is 45<50. So student A must choose school 1 as his first choice. By the same reasoning, student B will also choose school 1 as her first choice.

Given this, if student C chooses school 1 as his first choice, then all the students will list school 2 as their second choice. Student C's payoff would be 60*（1/3）+45*（1/3）+25*（1/3）=130/3<45, where the latter number is the payoff when he puts school 2 into his first choice and surely go to school 2 given the above choice of student A and B. So student C must put school 2 as his first choice in equilibrium

Now consider the second choice of each student. Student A and B would not choose school 3 as their second choice, otherwise student C would choose school 1 as his first choice and get an expected payoff as 60*1/3+45*2/3=50>45, where the latter number is his equilibrium payoff. Furthermore, if only one of student A and B choose school 3 as their second choice, student C, by choosing school 1 as his first choice, would get an expected payoff as 1/3*60+1/3*45+1/3*(1/2*45+1/2*25)=140/3>45. Thus he would still put school 1 as his first choice, which is not his equilibrium strategy. So, in the equilibrium, both student A and B should put school 2 as their second choice.

Given student A and B's equilibrium strategy as (1, 2, 3), and student C's first choice (school 2) in equilibrium, student C's second and third choice do not matter for his payoff: he will always go to school 2.

Under the equilibrium, student A and B will go to school 1 and 3 with equal probability, and student C will surely go to school 2.■