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Telling the Truth May Not Pay Off: An Empirical Study of Centralized University Admissions in Germany

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Abstract

Matching university places to students is not as clear cut or as straightforward as it ought to be. By investigating the matching algorithm used by the German central clearinghouse for university admissions in medicine and related subjects, we show that a procedure designed to give an advantage to students with excellent school grades actually harms them. The reason is that the three-step process employed by the clearinghouse is a complicated mechanism in which many students fail to grasp the strategic aspects involved. The mechanism is based on quotas and consists of three procedures that are administered sequentially, one for each quota. Using the complete data set of the central clearinghouse, we show that the matching can be improved for around 20% of the excellent students while making a relatively small percentage of all other students worse off.

KEYWORDS: matching, university admissions, strategic behavior

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1 Introduction

Matching students to universities has always been beset with some difficulties. In this paper, we analyze a new class of matching problems for a college admissions procedure that is based on three distinct quotas. Within each quota, a different criterion, such as the average grade or a certain social characteristic, is applied. These quotas are filled sequentially and, in principle, every applicant is considered under all quotas. This is the matching scheme that is currently employed by the German central clearinghouse for university admissions in medicine and related subjects.

The sequential matching scheme employed by the clearinghouse provides incentives to behave strategically. This is particularly true for applicants with excellent grades. These strategic aspects have important implications for the matching outcome: To the extent that applicants do not understand the strategic incentives of the matching scheme, the procedure designed to give excellent applicants an advantage in the admission process can harm them instead.

The impetus of our study lies in its contribution to the analysis of existing centralized matching schemes in markets of admissions to public schools and universities. While the German case is of specific interest for policy-makers in Germany, centralized institutions for university admissions also exist in other countries – for example, the United Kingdom, France, the Netherlands, and Turkey[1] – some of which use similar matching schemes. The German clearinghouse uses the well-known Gale-Shapley algorithm and the Boston mechanism, a priority matching scheme used by many school districts in the U.S. to assign children to public schools. The distinguishing feature of the mechanism we analyze is that these widely used algorithms are applied sequentially and that applicants can submit different rank-order lists for each of the three procedures. We can therefore directly observe whether the lists differ and how they are affected by the matching algorithm and by the sequence of the procedures.

The three procedures were created to fill the three different quotas. In particular, the procedures are designed (1) to give students with excellent grades a very good chance to be admitted to their preferred university, (2) to admit students with long waiting times, and (3) to allow universities to admit students according to their own preferences. In the first two procedures the Boston algorithm, and in the third procedure the college-proposing Gale-Shapley algorithm, are applied.

[1] In the U.K., universities pick students themselves, but the application procedures are centralized at UCAS (http://www.ucas.ac.uk). In France, a central clearinghouse handles applications to universities as in the U.K. with the special feature that several rounds of offers, rejections, and new offers are possible (see http://www.admission-postbac.org). In the Netherlands, a centralized matching scheme is used for about 50% of all seats. For a study of the mechanism used in Turkey see Balinski and Sönmez (1999).

Both of these algorithms have been widely studied in the literature and we will review them in due course.

Within the current procedure, so-called school choice and college admissions procedures are combined. In college admissions, universities state their own preferences over applicants (as in the third part of the current mechanism) whereas in school choice schools are duty bound to admit students according to a set of preordained priorities (as under the quotas for students with excellent grades or long waiting times).

We investigate the applicants' incentives and behavior under the matching mechanism and assess the stability and efficiency of the resulting matching. It is straightforward to show that the overall mechanism, encompassing the three procedures, is not strategy-proof. That is, revealing one's true preferences is not a dominant strategy. Using detailed records on students' choices, characteristics, and assignments, we empirically study whether the preference lists submitted by applicants reflect their true preferences or, alternatively, whether students submit manipulated lists. By doing so, we evaluate to what extent applicants understand the strategic properties of the application process.

The rationale for focusing on strategic behavior is that these choices affect the matching outcome. While certain forms of strategic behavior can lead to inefficient and unstable outcomes, other types of manipulations are necessary to achieve an efficient and stable matching. In particular, the first procedure will harm rather than help excellent students if top students fail to fully understand the strategic properties of the mechanism and thus do not manipulate their rank-order lists accordingly.

The main results can briefly be summarized as follows. We test three hypotheses regarding the strategic behavior of applicants. First, we demonstrate that due to the Boston algorithm applied in the first two procedures, a considerable number of applicants manipulate their preference lists for these two quotas so that it is consistent with the incentives created by the algorithm. As the Boston algorithm assigns as many applicants as possible to their first choice and considers second choices only if there are still seats left after the first round, students refrain from listing very popular universities on lower ranks of their list.

Our second and third empirical tests make use of the fact that the mechanism consists of three separate procedures applied sequentially. The criteria used in the three procedures differ, and for each of the procedures students can submit a separate list ranking their preferred universities. We find evidence that the preference lists submitted differ substantially between the procedures. Moreover, the differences between the lists can be explained with the respective criteria applied for the three quotas, which indicates strategic considerations by the applicants.

Finally, we show that a significant proportion of applicants with excellent grades truncate their preference lists in the first procedure. They do that because they do not want to be matched too early, since only those students who were not matched previously are considered in subsequent procedures of the mechanism. Excellent applicants expect to have another chance to get into their preferred university under the quota where universities select the students according to their own criteria. As we will demonstrate, such truncated lists in the first procedure are necessary to achieve a stable matching. As a downside, truncations by excellent students lead to excessive admission of students with long waiting times at the expense of students with good but not excellent grades.

In order to evaluate the efficiency of the matching, we run simulations. After inferring the true preferences of students from the submitted rank-order lists, we can compare the allocations achieved by different mechanisms and strategies. Our main finding is that excellent students are made worse off by the quota for excellent students. The matching of students with excellent grades could be greatly improved simply by removing this quota and moving the open seats to the procedure where the universities select students themselves.

The plan of the paper is as follows. The next section briefly reviews the related literature. We then describe the rules currently applied by the central clearinghouse and analyze the incentives of applicants to misrepresent their true preferences. Three hypotheses are formulated that can be tested with the data. In Section 4, we describe the data set used, and in Section 5 we report on a number of tests designed to understand whether individuals behave strategically. Section 6 analyzes the efficiency and stability of the current as well as alternative mechanisms, and in Section 7, we discuss possible ways to improve the mechanism. Section 8 concludes.

2 Related Literature

Our study is most closely related to Abdulkadiroglu, Pathak, Roth and Sönmez (2006) who investigate the strategic behavior of applicants for school seats in Boston, using data from the actual admissions process, as we do. But because the German mechanism differs from the algorithm employed in Boston, we have developed a number of new methods to detect strategic choices. In addition, the possibility to submit a different preference list for each of the three procedures allows us to use the variation in stated preferences *across* procedures to test for strategic behavior. Moreover, as we argue in Section 6, the specific properties of the German mechanism allow us to infer the true preferences from the rank-order lists submitted by the students. With simulations, we can therefore evaluate the efficiency and stability of the mechanisms.

Among the first studies to evaluate a matching algorithm empirically is an analysis of the mechanism to allocate Harvard student housing (Collins and Krishna, 1997). An interesting feature of this study is that questionnaires are used to elicit information about the true preferences which were then compared to the lists submitted.

University admissions in the U.S. have been studied with a focus on the strategic behavior of applicants in response to the rules governing early applications (Avery, Fairbanks, and Zeckhauser, 2004). Colleges are more likely to admit an early applicant than a regular applicant with the same qualifications and the main reason for applicants to apply early is to therefore increase their chances of being admitted. As a second indicator of strategic behavior, Avery et al. observe that when Stanford and Yale switched from Early Decision to Early Action,[2] the number of early applicants to those universities increased dramatically.

Our hypotheses regarding the applicants' strategic choices are supported by the findings of Westkamp (2009) who provides a theoretical analysis of the German mechanism for university admissions. Moreover, we can draw on the results by Roth (1991), who considered priority matching algorithms in the context of markets for doctors in Britain, and we make use of the results by Roth and Vande Vate (1991) as well as by Roth and Peranson (1999) regarding the strategic properties of the college-proposing Gale-Shapley algorithm.

A number of studies analyze the Boston mechanism. While the outcome of the Boston mechanism is Pareto efficient if all applicants submit their true preferences, it is not in the best interest of applicants to do so (Abdulkadiroglu and Sönmez, 2003). Given strategic choices, the set of equilibrium allocations of the Boston mechanism is weakly dominated by the student-optimal stable matching (Ergin and Sönmez, 2006). If there are sincere applicants who report their true preferences and sophisticated players who play a best response, then sophisticated students can be better off in the Boston mechanism than in the student-optimal stable mechanism (Pathak and Sönmez, 2008).

The theoretical literature has been complemented by experimental evidence. In general, the Boston mechanism performs poorly in the lab when compared to Gale and Shapley's deferred-acceptance mechanism (Chen and Sönmez, 2006). Experiments by Pais and Pintér (2008) find a positive correlation between the amount of information available and the proportion of strategic choices in the Boston mechanism. These studies highlight the problem of strategic behavior under the Boston mechanism and are able to quantify the inefficiencies created by the Boston mechanism in the lab.

[2] With Early Decision, applicants are only allowed to apply to one specific university. With Early Action, students are allowed to apply to several universities.

Finally, the Gale-Shapley student-optimal stable mechanism can be combined with flexible type-specific quotas (Abdulkadiroglu and Sönmez, 2003). The main difference to our mechanism is that students can only belong to one type, and are therefore only eligible for a single quota.

3 The Student Mechanism

Under the German system, university admissions for medical subjects are all centrally administered. Prospective students of biology, medicine, pharmacy, psychology, animal health, and dentistry have to send their application to the central clearinghouse. Students can apply only in one of the six fields administered by the clearinghouse but are free to apply additionally in any field not administered by the clearinghouse.[3]

The central clearinghouse assigns students according to the following three procedures that are implemented in a sequential order:

(1) *Procedure A* admits students who are top of the class to around 20% of all seats.
(2) *Procedure W* admits students with long waiting times to around 20% of all seats.
(3) *Procedure U* represents admission by universities according to their own criteria to around 60% of all seats.[4]

For each of these procedures, applicants are asked to submit a preference ranking of universities. They are allowed to rank no more than six universities in procedures A and U. Only in procedure W do they have the option to add all other universities to the bottom of their list without ranking them.

All three procedures are **two-stage procedures**. At the first stage, applicants are selected ("selection"). At the second stage, the selected applicants compete for admission to one of their preferred universities ("admission"). At this second stage, the Boston mechanism is applied in procedures A and W while in procedure U the college-proposing Gale-Shapley mechanism is used. When submitting their preference lists, applicants do not know for certain whether they will be selected in the first stage of any of the three procedures.

[3] Some years ago, subjects such as business administration, economics, and architecture were also administered by the central clearinghouse, but they were decentralized as soon as the number of applicants dropped relative to the number of open seats. The introduction of the Bachelor's degree instead of the diploma in biology and psychology implies that from the winter term 2009/10 on, the central clearinghouse administers only the four remaining subjects. We are grateful to Bernhard Scheer of the ZVS for this information.

[4] The German terms for the three procedures are *Abiturbestenverfahren, Wartezeitverfahren,* and *Auswahlverfahren der Hochschulen.*

After conducting the admission process, the central clearinghouse publishes detailed information on the application characteristics of admitted candidates for every university-subject combination. This includes the minimum requirements in terms of grade, waiting time, and/or social criteria for a successful application. Hence applicants are informed about the popularity of the different subjects and universities within the three procedures in previous years. We expect that applicants use this information about the past and compare their characteristics to historical thresholds when making their choices.

3.1 Procedure A

Procedure A is employed to reward excellent average grades in the *Abitur* (i.e., the average final grade from secondary school). In order to fill the quota for excellent students, applicants with the best average grades are selected at the first stage of the procedure.[5] Whether an applicant is selected or not only depends on his personal characteristics, that is, on the average final grade from school and possibly on subordinated criteria.[6] His or her stated preference ranking of universities cannot influence the outcome of the selection stage. In our analysis, we will concentrate on the second stage, at which the selected applicants compete for admission to one of their preferred universities and at which stated preferences matter. The admission algorithm assigns as many applicants as possible to their first choice and considers second choices only if there are still seats left at the end of the first round.

More specifically, the algorithm of procedure A can be described as follows:

Step *1*: Only the first preferences of the applicants are considered. For each university, admit the selected applicants who have ranked it as their first choice, until there are no seats left or until all candidates ranking this university as their first choice have been admitted. If there are more candidates giving priority to a university than can be admitted, those applicants with the best grades in the *Abitur* are admitted. Social criteria and (subordinately) lotteries are used to break ties.

[5] Due to the federal structure of the German educational system, every federal state in Germany has its own *Abitur* with its particular combination of subjects and grading system. In order to guarantee equal chances of admission to universities in spite of the federal school system, competition for admission is not nationwide but takes place only among applicants who have passed their *Abitur* in the same federal state. A detailed description of the selection stage can be found in Braun and Dwenger (2009).

[6] Subordinated criteria for selection are waiting time, military or civil service, and a lottery.

Step k: Only the k^{th} preference of the still unassigned applicants is considered. For each university with available seats, admit the selected applicants who have ranked it as their k^{th} choice, until there are no seats left or until all candidates ranking the university as their k^{th} choice have been admitted. If there are more candidates giving the rank k to a university than can be admitted, those applicants with the best average final grade from school are admitted. Social criteria and (subordinately) lotteries are used to break ties.

The algorithm stops after step $k \leq 6$ when every selected applicant is assigned or when all *6* preferences have been considered. This means that some applicants may have been selected but remain unassigned even though there are still open seats at some universities. This is the case when universities with open seats have not been listed by the unmatched applicants.

Note that the algorithm does not eliminate **justified envy** (see Example 1 in the appendix)**.** A matching can result in which an applicant prefers to be matched with a certain university over his actual matching outcome, and the university prefers this applicant over the applicant whom it has actually admitted. In addition, under the Boston mechanism it is not a dominant strategy to state one's preferences truthfully. In procedure A (and in procedure W, too, as we will see in the following), an applicant ranking a university in k^{th} position is admitted before applicants ranking a university in $(k+1)^{th}$ position are considered – independently of her average grade. Hence, it may be advantageous for applicants to manipulate their true preference ordering.

In a leaflet, the German central clearinghouse points out that the chances of being admitted depend on the rank-order submitted (ZVS, 2006a, translated by the authors):

"If you could not be admitted to your top university, the central clearing house considers your second preferred university. However, at this university priority is given to all those applicants who top-ranked this university. This means that your chances of being admitted at a lower ranked university are worsened depending on the overall demand."

3.2 Procedure W

Procedure W is employed to reward the number of terms an applicant had to wait for admission since finishing secondary school.[7] First, the applicants with the

[7] The procedure based on waiting time fulfils the requirement of the German constitutional court's ruling on university admissions (Numerus-clausus-Urteil, 1972, BVerfGE 33, 303). It stipulates that the admission criteria have to be such that in principle every applicant, who holds the right to enter a university (e.g., through passing the *Abitur*), has a chance to be admitted.

longest waiting times are selected.[8] At the second stage, admission is organized based on stated preferences and using the Boston mechanism just as in procedure A. The only difference between procedure A and W is the set of criteria applied to break ties between applicants giving the same rank to a university that does not have enough seats left to admit all of its applicants. In procedure W, emphasis is put on social criteria, the most important being the proximity of a university to the parents' house.[9] Second preferences are again only considered if there are still seats left after the first round. This implies that procedure W is not strategy-proof either.

To analyze behavior in procedures A and W, we adapt a definition of Abdulkadiroglu, Pathak, Roth and Sönmez (2006) to our context:

Definition: A university is over-demanded for a given subject and within a given procedure if only selected applicants who have ranked the university as their first choice have a chance of being admitted.

By this definition, the number of applicants ranking an over-demanded university as their first choice will exceed the number of seats available. Thus, it is never successful to rank this university second or lower. For each subject and university, applicants are informed about the previous years' preferences, grades, and social criteria that were necessary to be admitted. These threshold values are highly correlated over the years. Therefore, we formulate

Hypothesis 1: In procedures A and W, students do not rank universities that are over-demanded at positions other than the first on their preference list.

In procedure W, there is an additional possibility for applicants to improve their match by strategic manipulations. The central clearinghouse (ZVS, 2006b, translated by the authors) advises the following strategic behavior:

"In practice, some universities are regularly over-demanded. That is to say, a large number of applicants want to study at a famous university or in an attractive university town. Many applicants therefore state one of these universities as their first preference even though this university is not the nearest

[8] Note that years of study are not accepted as waiting time. Lower-ranked criteria used to break ties at the selection stage are average grade, completion of military or civil service, and a lottery.

[9] Students are priority ordered in the following way: (i) severely disabled applicants, (ii) applicants with a spouse/child having their main residence close to the university, (iii) applicants with particularly mandatory links to the university town, (iv) applicants registered at their parents'/ foster parents' house and who want to study at the closest university, and (v) other applicants. Average grade and (subordinately) lotteries are used to break ties within each group.

one offering the desired subject; in this case these applicants are of priority order 5 for universities which are far away. This means that a large number of applicants living with their own family or with their parents and having stated the nearest university will be considered with priority. Most applicants have little chance to be admitted outside their catchment area."

In procedure A, there is no such incentive as the final grade from school is used to break ties. The following hypothesis will therefore be tested empirically:

Hypothesis 2: The percentage of applications to the closest university is higher in procedure W than in procedure A since in W the proximity of the university to the parents' home is one of the tie-breaking criteria.

Such manipulation of preference lists in procedure W can lead to inefficient outcomes (see Example 2 in the appendix).

3.3 Procedure U

Universities are given the opportunity to select the majority of their students themselves in procedure U, with the final grade from school as the predominant, but not the only, criterion. Procedure U is a two-stage procedure if a university decides to pre-select its applicants before the admission process (i.e., this pre-selection stage is optional).[10] We focus here on the admission process only because our data set does not provide sufficient information to study the pre-selection process empirically.

At the admission stage, each university ranks the (possibly) pre-selected applicants who have listed it using the final grade from school as the main criterion.[11] Unlike in procedures A and W, this is a two-sided market where both students and universities have preferences over their match and possibly act strategically. Given the preference lists of universities and students, the central clearinghouse applies the college-proposing Gale-Shapley algorithm on the set of pre-selected applicants. The algorithm was first described by Gale and Shapley (1962) although similar ideas had been in use since the 1950s in the U.S.

[10] Pre-selection can be delegated to the clearinghouse which then shortlists applicants according to the preference rank the applicant has given to the university and the average grade in the *Abitur*. The pre-selection criteria applied by the universities differ, requiring for example that the university be listed as a first preference or first to third preference. Some universities use a combination of average final grade and preference rank, e.g., only applicants who are among the best 300 applicants listing the university first or second are pre-selected.

[11] Additional admission criteria used by the universities are the weighted average of grades from school which reflect necessary qualifications for the subject, the result in a subject specific scholastic aptitude test, and an apprenticeship in an area related to the subject.

clearinghouse for the first jobs of doctors (see Roth, 2008).[12] The college-proposing Gale Shapley mechanism works as follows:

Step *1*: Each university i with capacity n_i offers a seat to the n_i applicants it ranks highest. Each applicant tentatively accepts the offer from the university she ranks highest and rejects all remaining offers.

Step k: Each university that was rejected at step k-1 by x applicants proposes to its most preferred next choices, with the number of new offers (x) being equal to the number of rejections in the previous round. Each applicant considers the university it has been holding an offer from together with her new offers and tentatively accepts the university she ranks highest and rejects all others.

The algorithm terminates when no proposal by a university is rejected. Each university and applicant is assigned according to the last tentative assignment. If for a certain seat a university is rejected by all applicants to which it has made an offer and there is no applicant left on its preference list, this seat remains unfilled.

The Gale-Shapley college-proposing algorithm in the college admissions problem leads to a stable matching: Everybody prefers their match over no match at all and there is no student and university who are not matched but who would both prefer to be. In addition, the mechanism leads to the stable matching that the universities prefer to all other stable matchings. However, the college-proposing Gale-Shapley mechanism is not strategy-proof for the applicants (Roth 1985).

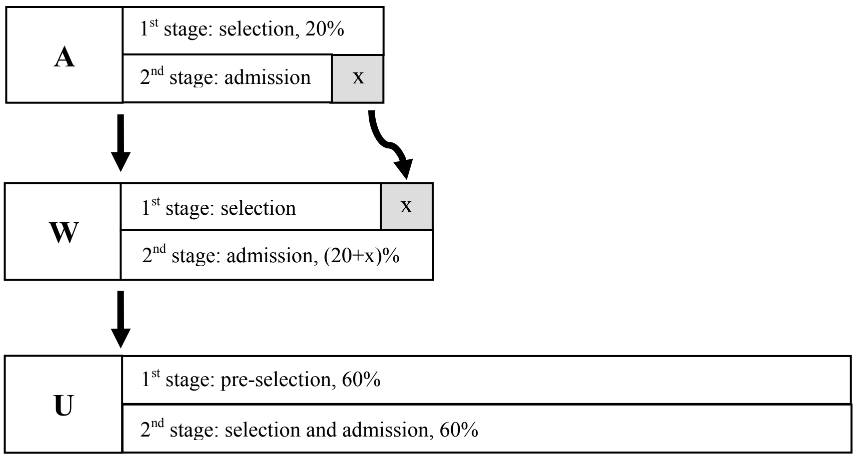
3.4 Relationship between the Procedures

The three procedures are implemented sequentially. First, procedure A is administered. Once applicants are admitted or rejected, procedure W is implemented for those applicants who are still unassigned. Finally, those candidates who have not been admitted either through procedure A or through procedure W participate in procedure U. Figure 1 illustrates the sequential ordering of the three procedures. As described above, open seats may remain in procedure A if not all selected applicants can be admitted to one of their preferred universities. These remaining seats, denoted by x in the figure, are moved to procedure W.[13]

[12] See Gale and Shapley (1962), Roth (1985) as well as Roth and Sotomayor (1990). For the related student placement problem where the priority at schools is determined by, e.g., exam scores see Roth (1982), Alcalde and Barberà (1994) as well as Balinski and Sönmez (1999).

[13] This feature has recently been changed. Open seats are now moved from procedure A to U.

Figure 1: Admission procedures – sequential order and fraction of seats allocated



Since procedures are not independent from each other, applicants not only have to consider strategic choices *within* a procedure but also *between* procedures. This problem is especially severe for applicants with a very good average grade from school, since they have a chance to be admitted both in procedure A and U. These students should avoid being matched to a less preferred university in procedure A as they have a very good chance to be admitted to one of their top choices in procedure U. This leads to

Hypothesis 3: Applicants selected in procedure A submit shorter rank-order lists of universities than (selected) applicants in procedures W and U because they know that they have a good chance to receive one of their most preferred universities in procedure U.

The truncation of lists in A can increase the efficiency of the mechanism and avoid an unstable matching. If a top student does not truncate his list but instead gets matched to his second choice in A, it is possible that his first-ranked university would prefer to be matched with him instead of being matched with some other student it has admitted in procedure U. Therefore, the matching is unstable.

In the information brochure, the central clearinghouse does not mention the possibility of such truncations. However, it provides comprehensive information about admissions in the previous year, which in principle enables applicants to calculate their chances of being admitted to a certain university in U.

Note that the incentive to list only universities that are not over-demanded at rank two and lower can be overruled by the incentive to truncate one's list in A. In other words, listing one's true preferences with many over-demanded universities in procedure A can have the same effect as a truncation and can therefore turn out to produce a better match for the applicants than a strategic re-ordering of universities in A. We can compare the relative success of both strategies with the help of the simulations reported in Section 6.[14]

4 Description of the Data

We use the information collected through our access to the anonymized database of the central clearinghouse covering all applications for the winter term 2006/07. The following six subjects are centrally administered and are part of our data set: biology, medicine, pharmacy, psychology, animal health, and dentistry. The data set records all information provided by the applicants including data on individual characteristics such as age, sex, and place of living. Applicants also report their final average grade from school, their waiting time since completing secondary school, information on military or social services, and other social criteria relevant for the selection process. Furthermore, the database provides information on the admission procedures a prospective student has participated in as well as his or her preferences concerning the subject and the place of study that have been stated for the different procedures. However, for procedure U the data set only contains information on the choices of relatively few applicants at the pre-selection stage. In addition, for procedure U we only know the rank of a university in an applicant's list if the applicant has been pre-selected for this university. These data deficiencies led us to disregard strategic behavior at the pre-selection stage in procedure U.

For each of the three admission procedures, success or failure of the application is reported. Applicants who have been selected in the first stage of the selection procedure (but were not necessarily admitted) can be identified by applying the selection criteria made public by the central clearinghouse (ZVS 2006c).

[14] Choices in A can, in principle, also be affected by the pre-selection criteria in U. As an example, suppose a top student has two favorite universities (with a slight preference for one of the two), and suppose she must list both universities first in procedure U in order to be pre-selected. Thus, she only has a chance of being pre-selected at one of the two universities in procedure U and might therefore consider listing both universities in procedure A. In contrast, without the pre-selection criteria of the two universities in U, it could be better for her to truncate her list in A to her most preferred university and hope to be admitted to one of her two favorite places in U. The ensuing hypothesis regarding longer lists in A, given that one's most preferred universities have strict and exclusive pre-selection criteria in U, could be tested empirically. But the relatively small number of cases renders an investigation of this hypothesis futile in our data set.

Table 1: Descriptive statistics, by admission procedure

	Procedure A		Procedure W		Procedure U	
	Selected	Not selected	Selected	Not selected	Accepted	Rejected
Personal characteristics						
Age (Years)	20.209	21.274	25.864	20.910	20.204	21.704
Female (fraction)	.724	.672	.614	.674	.707	.659
Grade	1.198	2.330	2.606	2.292	1.802	2.472
Waiting time (semester)	.673	2.210	9.035	1.649	.735	2.817
Subject preferences (fraction)						
Biology	.137	.078	.176	.065	.193	.032
Medicine	.441	.499	.412	.511	.376	.549
Pharmacy	.094	.057	.095	.053	.097	.044
Psychology	.192	.202	.20	.198	.207	.197
Animal Health	.057	.080	.047	.085	.054	.090
Dentistry	.079	.084	.066	.088	.072	.090
N	3,274	58,043	6,024	54,911	17,470	45,288

After excluding from the data set those applicants who did not finish secondary school in Germany, we are left with a total number of 65,254 observations.[15] Almost every applicant has submitted a preference list for each of the three procedures. In fact, 61,317 prospective students have chosen to take part in procedure A, 60,935 in procedure W, and 62,758 have supplied a preference list for procedure U. For each application procedure, the descriptive statistics in Table 1 contrast the characteristics of those applicants that have been selected at the first stage with those of the unsuccessful candidates.[16]

The table illustrates the different selection criteria applied in the three procedures. Applicants selected in procedure A have received extraordinarily good final grades in school. While candidates successful in procedure U performed somewhat worse, they still outperform the rejected applicants by their good final grades. Students selected in procedure W, in contrast, are characterized by a relatively poor performance in school, but they have been waiting for a seat at a university for a long time. The table also shows that the largest share of applicants are potential medical students, and that subject preferences matter for the success probability of an application.

[15] In Section 5.2 we make use of the fact that in procedure W the proximity of an applicant's place of living to the preferred university is used as a (subordinated) admission criterion which may induce strategic behavior. Since this criterion is never fulfilled by students living abroad, we have restricted the data set as described.

[16] Since the pre-selection step is not obligatory for universities in procedure U, only the characteristics of accepted and rejected students are compared for this procedure.

5 Empirical Evidence of Strategic Behavior

As a first step towards evaluating the performance of the assignment mechanism, we compare stated preferences and slots received by the selected candidates. In Table 2, we simply count the number of times where the first preference of an applicant is satisfied, the number of times the second preference is satisfied, and so on. In procedure A, 58.3% of the selected students are admitted to their first preference. In procedure W, this percentage is similar at 61.8%. Notice that the second to sixth preference are only rarely satisfied in both procedures. This is a direct effect of the Boston algorithm in procedures A and W, which gives priority to those students who have listed a university as their first choice.

However, stated and true preferences may not coincide. Therefore, the fraction of students who are assigned to their first choice cannot be taken as a measure of success. In what follows, we investigate to what extent behavior observed in the data is consistent with the incentive to act strategically. The main difficulty for studying strategic behavior empirically is the unobservability of the applicants' true preferences. Testing the three hypotheses developed in Section 0 provides us with indirect evidence on the question of whether students reveal their preferences truthfully or whether they behave strategically. In Section 6, we will then infer the true preferences from the lists submitted by each applicant. This allows us to compare the efficiency and stability of the current mechanism with alternative mechanisms. We will thereby be able to evaluate the quantitative importance of the strategic responses for overall efficiency.

Table 2: Preference received by applicants fulfilling selection criteria

	Procedure A		Procedure W	
	Number	Per cent	Number	Per cent
1^{st} preference	1,909	58.33	3,723	61.80
2^{nd} preference	214	6.54	395	6.56
3^{rd} preference	80	2.44	198	3.24
4^{th} preference	54	1.65	114	1.89
5^{th} preference	57	1.74	104	1.73
6^{th} preference	27	0.82	61	1.01
Other preference	-	-	447	7.42
Unassigned	933	28.48	982	16.30
	3,274	100.0	6,024	100.0

5.1 Strategic Preference Ordering Within Procedures

First, we test **Hypothesis 1** stating that under the Boston mechanism it is suboptimal to state an over-demanded university at any preference rank other than the first. For the empirical analysis, we have created a dummy for each stated preference indicating whether or not the university listed was over-demanded for the chosen subject within the procedure considered in the previous year. This information is publicly available from the central clearinghouse (ZVS 2006c), and applicants can be expected to be familiar with this information prior to their choice.

Table 3 presents the percentage of over-demanded universities at each rank of the preference list for procedures A and W.[17] The table reveals that both among all and among selected applicants in procedures A and W, the fraction of over-demanded universities is largest in the first preference stated.[18] The fraction clearly drops from the first to the second preference, for example, by 7.2 percentage points among selected applicants in procedure A and by 8.4 percentage points among selected applicants in procedure W. The differences between adjacent preference ranks further down the list are usually much smaller than the drop observed between the first and the second preference.[19] This is consistent with a number of students understanding that they should never rank over-demanded universities at the second to sixth place.

[17] If this table is constructed only for those applicants who have listed 6 universities, the same qualitative pattern emerges.

[18] Also note that selected applicants choose over-demanded universities more often than all applicants together. This effect is particularly strong in procedure A with 53.7% of all applicants and 68.2% of the selected applicants ranking an over-demanded university first. If the selected applicants are a random sample with regard to their preferences, then this hints at strategic considerations of the applicants who submit a list of preferences that depends on their own grade in procedure A.

[19] This observation also rules out that the observed drop simply results from the fact that once an over-demanded university is chosen at the first preference rank, the pool of over-demanded universities shrinks and, hence, the likelihood of choosing an over-demanded university at the second rank decreases as well. In particular, similar drops should then also be evident for ranks further down the list. Importantly, the pool of over-demanded universities is quite large. In fact, at about 41.0% (58.3%) of all university-subject combinations are over-demanded in procedure A (W). Hence, even after choosing an over-demanded university the applicant is left with a considerable number of potential choices that are over-demanded as well.

Table 3: Fraction of universities over-demanded in the previous year in stated preferences

	Procedure A		Procedure W	
	All applicants	Selected applicants	All applicants	Selected applicants
All applicants				
1st preference	.537	.682	.617	.654
2nd preference	.479	.610	.555	.570
3rd preference	.453	.593	.537	.538
4th preference	.456	.552	.531	.526
5th preference	.433	.497	.505	.507
6th preference	.414	.501	.495	.501

An alternative approach to the question of how often over-demanded universities are ranked first, second or lower is to take every subject-university combination as a unit of observation. In order to detect strategic preference orderings of the applicants we run the following regression:

$$\frac{Pref_{ijkt} - Pref_{ijlt}}{Pref_{ijkt} + Pref_{ijlt}} = \beta_0 + \beta_1 OverDemanded_{ij(t-1)} + \beta_2 PopGrowth_{it} + \beta_3 City_{it} + \varepsilon_{ijt}$$

with $t = 2006$. This allows us to test the theoretical prediction that over-demanded university-subject combinations are more likely to experience a drop between the numbers of applications ranking it first and second. As the dependent variable at time t, we take the difference between the number of applications ranking university i for subject j at positions k and l normalized by the total number of applications at the two adjacent ranks. Accordingly, the variable to be explained is bounded by ± 1 and takes a value of 0 in case of a balanced number of applications at the two ranks considered. The normalization ensures that the dependent variable is not influenced by the size of a university. Otherwise, we would risk biased estimates given that the probability of a university being over-demanded may be related to its size.

The dependent variable is regressed on the dummy $OverDemanded_{ij(t-1)}$ indicating whether or not subject j has been over-demanded at university i in the previous year.[20] As further explanatory variables we include the (yearly)

[20] By using information from the previous rather than from the current year, we not only capture much better the information available to applicants but we also avoid potential endogeneity biases. If we had instead relied on information from the current year, an observed drop between the number of applications ranking a university first and second would not necessarily have implied strategic behavior but might have simply hinted at a large number of applications ranking the university at position one, which, by definition, causes the university to be over-demanded. When

population growth of the city a university is located in (*PopGrowth*$_{it}$) and a dummy indicating a population size of above 500,000 inhabitants (*City*$_{it}$) at time *t*. Both variables are meant to proxy the attractiveness of the city environment, which is likely to influence applicants' behavior. Furthermore, a full set of subject dummies is included.

The results of OLS estimations for both procedures, A and W, are presented in Table 4. As expected, the estimated coefficient of the dummy for being over-demanded is positive and highly statistically significant in the regression on the difference between ranks 1 and 2. This applies to both application procedures but not to ranks further down the preference list.[21] Therefore, the difference between the number of applications ranking a university-subject combination first and second is significantly higher for over-demanded combinations. This is consistent with a significant proportion of students understanding that they can list an over-demanded university-subject combination first, but that they should not list it at any other preference rank.

The question arises why there are still so many students who rank over-demanded universities at ranks 2 to 6. Of course, many applicants may not understand the strategic incentives. In addition, the data show that only around 72% (procedure A) or 81% (procedure W) of the universities that were over-demanded in 2006/07 were also over-demanded in 2005/06. Thus, some applicants may speculate that a university which was over-demanded in the previous year might not be over-demanded in the current year and therefore list it at a lower rank. Finally, and as discussed in more detail in Section 3.4, the incentive to list only universities that are not over-demanded at rank two and lower can be overruled if the applicant has a good chance of obtaining her preferred choices in procedure U.

basing the classification of university-subject combinations as over-demanded on the number of applications from the previous year, there is no such issue of reverse causation.

[21] The dummy is also significant at the 10%-level in the regression on the difference between ranks 3 and 4 in procedure W. However, the coefficient is comparably small and no such effect is found for procedure A.

Table 4: Preference discontinuities – Regression results

	Dependent Variable: $(Pref_{ijkt} - Pref_{ijlt}) / (Pref_{ijkt} + Pref_{ijlt})$				
(k,l)	(1,2)	(2,3)	(3,4)	(4,5)	(5,6)
	Procedure A				
Over-demanded in	.1146***	.0171	.0180	.0088	.0048
previous year	(.0349)	(.0298)	(.0295)	(.0195)	(.0139)
City	.1052***	.0317	.0088	.0228	.0006
	(.0339)	(.0294)	(.0268)	(.0145)	(.0132)
Population Growth	.0074	-.0347	-.0360	-.0106	.0028
	(.0433)	(.0463)	(.0490)	(.0227)	(.0206)
Constant	-.0071	.0766*	.0776*	.0617***	.0591***
	(.0435)	(.0432)	(.0405)	(.0176)	(.0183)
Subject Dummies	Yes	Yes	Yes	Yes	Yes
R^2	.1689	.0320	.0381	.0593	.0286
	Procedure W				
Over-demanded in	.0988***	.0394	.0253*	.0131	-.0023
previous year	(.0334)	(.0274)	(.0274)	(.0208)	(.0190)
City	.0873**	.0527*	.0068	.0037	.0037
	(.0349)	(.0290)	(.0264)	(.0169)	(.0159)
Population Growth	.0099	-.0531	.0132	-.0200	-.0287
	(.0428)	(.0324)	(.0379)	(.0254)	(.0282)
Constant	-.0237	.0274	.0148	.0189	.0452
	(.0451)	(.0438)	(.0349)	(.0222)	(.0372)
Subject Dummies	Yes	Yes	Yes	Yes	Yes
R^2	.1471	.0677	.0162	.0311	.0217
N	144	144	144	144	139

***, **, *: statistically significant at the 1, 5, 10 percent level. Robust standard errors are reported in parentheses.
$Pref_{ijkt}$: Number of Applications Ranking University *i* for subject *j* at position *k* at time *t*.
City dummy indicates a population size of above 500,000 inhabitants at time *t*.
Population growth gives the (yearly) population growth of the city a university is located (at time *t*).

5.2 Stability of Preferences across Procedures

If applicants revealed their preferences truthfully, stated preferences should not vary across the three procedures. However, the criteria employed to admit applicants differ between the procedures, and it can therefore be rational for an applicant to submit different preference lists.

Table 5 reports the discrepancies between the lists applicants submit in the three procedures A, W, and U. Discrepancies at a certain preference rank can result either from naming different universities or from not stating a preference in one list, but stating one in the other list. Even when restricting attention to the first case, the results in Table 5 show that a considerable number of subjects submit different lists. This holds for all three comparisons between the procedures at all preference ranks, displaying between 13% and 30% different choices. Using a one-sided *t*-test we find that these differences are significantly larger than zero at all conventional levels.

Table 5: Fraction of applicants naming a different university at a certain preference rank (without truncations)

	Procedures		
	A vs. W	A vs. U	W vs. U
1st preference	0.135	0.188	0.221
2nd preference	0.184	0.254	0.289
3rd preference	0.202	0.271	0.306
4th preference	0.208	0.267	0.303
5th preference	0.200	0.252	0.285
6th preference	0.184	0.218	0.254

We now take a closer look at the question of whether different selection criteria lead to the observed differences in the preference lists. Given our data set, this can best be seen when comparing procedures A and W. Quantitatively the most important subordinated criterion for admission in procedure W is whether a student who lives with his parents applies to the closest university. While this information is not provided directly in the data set, we can identify the university closest to an applicant's place of living. We then compare the fraction of applicants in the two procedures that list their closest university. By doing so, we can test **Hypothesis 2** according to which the percentage of applications to the closest university is higher in procedure W than in procedure A.

Table 6: Fraction of applicants with preference for closest university

	1st preference	2nd preference	3rd preference
Procedure A			
All applicants	.521	.167	.085
Selected applicants	.499	.148	.089
Procedure W			
All applicants	.533	.171	.086
Selected applicants	.653	.190	.082

Hypothesis 2 is clearly supported by the data as can be taken from Table 6. The effect is relatively small for all applicants. Nevertheless, a two-sample test of proportion reveals that the fraction of applicants listing their closest university first, second or third is significantly higher for procedure W than for A on all conventional significance levels. The difference increases considerably when only selected applicants are considered. Since selected applicants have a realistic chance of being assigned in the respective procedure, A or W, they have a strong motive to optimize their preference orderings and thus behave strategically.[22]

5.3 Truncated Preference Lists

A considerable number of students remain unassigned in procedures A and W, even though they fulfill the selection criteria. The number is particularly high in procedure A where more than one-quarter of the selected students are not admitted to any university. This observation is in line with the incentive to go for the top choice(s) in procedure A and, in case of no success, hope to be admitted in procedure U (as formulated in **Hypothesis 3)**.

In fact, 99% of the selected students who remained unassigned in procedure A obtained a seat at a university; the overwhelming majority even obtained their top choice in procedure U. To take a closer look at the applicants' behavior, Table 7 displays the percentage of students who list only one university, only two universities, etc. in procedures A and W.

Table 7: Number of universities ranked by applicants

	Procedure A		Procedure W	
Number of universities ranked	All applicants	Selected applicants	All applicants	Selected applicants
1	.111	.261	.089	.172
2	.061	.097	.041	.065
3	.075	.118	.043	.059
4	.055	.080	.026	.032
5	.096	.081	.082	.051
6	.602	.364	.720	.621
N	61,317	3,274	60,935	6,024

Almost all students supply a rank-order list for procedures A and W even if their chances of being selected are virtually zero. The second and fourth columns of Table 7 show that the majority of all students submit a list of six universities, but that significantly more students truncate their preference lists in procedure A than in procedure W. The difference widens considerably when we look at selected students only. In procedure A (third column) more than a quarter

[22] One potential problem of the analysis is that applicants selected in the two procedures may systematically differ from each other with respect to their inclination to move away from their home town. Since the two groups of selected students in procedures A and W are almost disjointed, we cannot tackle the problem by analyzing the behavior of candidates selected in both procedures. Instead, we checked (and confirmed) the robustness of our results by means of a regression analysis controlling for observable characteristics that should arguably be correlated with individual mobility. Detailed regression results can be obtained from the authors upon request.

of the selected students only list one university and only 36% list six universities. In contrast, 62% of the applicants selected in W name six universities on their rank-order list.[23] In procedure W, no analogous incentive to truncate the list exists because the successfully selected students in procedure W usually have such poor grades that they have no chance of being admitted through procedure U. A two-sample test of proportion reveals that for both, all applicants and selected applicants, the difference between A and W is statistically significant at any conventional level.

Table 7 also reveals that many selected applicants do not submit truncated lists in procedure A. They could either be risk-averse or indifferent among a number of universities. In addition, the strategic incentives are probably not clear to all applicants.[24] We will come back to the effect of such choices on the matching outcome in Section 6.

Table 8: Fraction of applicants submitting truncated preference lists, by grade

Grade	Procedure A
1.0 - 1.2	.602
1.3 - 1.5	.496
1.6 – 1.8	.406
1.9 – 2.1	.319
≥ 2.2	.390

As we have seen, selected applicants tend to truncate their submitted preference lists more often in procedure A than in procedure W. This is in line with Hypothesis 3. We even expect that the incentives to truncate vary by grade in procedure A, since excellent applicants can be confident of getting a seat in procedure U. Weaker candidates, in contrast, may be less certain about their chances in the final procedure and therefore less inclined to play a (potentially risky) truncation strategy earlier on. In accordance with this hypothesis, Table 8 provides clear evidence that the fraction of truncated preference lists is increasing with school performance in procedure A.

Another test of truncations can be provided by only considering applicants who have been selected in procedure A and by comparing the length of their lists in procedure A and in procedure U. We find that in this group, the percentage of

[23] The still surprisingly large number of selected applicants in W who truncate their list may be explained by the fact that these applicants have been waiting a number of years to be admitted and might therefore have stronger obligations and preferences for living in a certain place than students with shorter waiting times.
[24] For example, the experimental study by Chen and Sönmez (2006) shows that about 20% of the participants use the suboptimal strategy of telling the truth under the Boston mechanism.

applicants listing only one university in procedure A is more than 10 percentage points higher than in procedure U.[25]

The choice to rank only one's first preference(s) in procedure A has two important side effects. First, around 28% of the slots the universities planned to fill through procedure A were not taken in procedure A because some universities were not listed often enough by applicants. And in 2006/07, the unfilled slots from procedure A were moved to procedure W. Thus, some universities received far more than 20% of their students through procedure W.[26] Since 2007 unfilled seats have been moved to procedure U instead. In this way, universities are able to admit students from the same pool as in procedure A, namely students with very good final grades.

The second effect of truncation strategies is that they can prevent inefficient and unstable matchings. Applicants who truncate their lists in procedure A avoid being matched to a university at a low preference rank in A although they would be admitted to a higher ranked university in procedure U. From this perspective, truncation strategies are necessary to correct deficiencies of the mechanism. In the next section, we will study the effect of truncations on the matching outcome with the help of simulations.

6 Efficiency and Stability: Evidence from Simulations

There is still one vital question to be addressed, namely whether the mechanism leads to an efficient matching. The unique property of the data set is that applicants submit three different lists and through this information we can infer the applicants' true preferences. Thus, we can evaluate the efficiency of the current mechanism and compare it to the efficiency of alternative mechanisms.

Before we present the results of our simulations, a number of remarks are in order. First, we restrict attention to procedures A and U because procedure W concerns only a disjointed set of applicants with poor grades and low chances of being admitted through the other two procedures. Thus, interesting interactions occur mainly between procedures A and U. In addition, applicants probably do not think very hard when filling out lists in procedures that are not relevant for them. This makes the lists submitted for procedures A and U by students with

[25] This difference is statistically significant at any conventional level. Notice that we might even underestimate the truncation effect since our data only contain lists for procedure U that have already been shortened due to the removal of universities for which an applicant has not been pre-selected. Detailed results can be obtained from the authors upon request.

[26] The number of students selected in procedure W is almost twice as large as the number of students selected in procedure A, as displayed in Table 7. This is due to the unfilled slots from procedure A which were moved to procedure W, but also to the fact that the clearinghouse "overbooks" seats in procedure W but not in procedure A to account for applicants not accepting an offer.

long waiting times and poorer grades less informative. We will therefore focus mainly on the selected applicants (as in the previous section) and on those applicants that have good chances of being admitted both in procedures A and U.

Second, in order to approximate the preferences of universities in procedure U, of which we lack the data, we take the final grade from school as the criterion by which universities rank students. As all universities have to use this grade as the main criterion (due to legal constraints) and some universities even base their ranking of applicants solely on the final grade, this approach seems justified.

Finally, we infer the applicants' true preferences from the rank-order lists submitted in procedure U which are possibly complemented by the lists submitted in A. The preferences submitted for procedure U should correspond to the (possibly incomplete) true preferences of the applicants for two reasons. First, in the college-proposing Gale-Shapley mechanism all successful manipulations can also be accomplished by truncations. Or, in other words, "every applicant who can do better than to submit his true preferences as his ROL [rank-order list] can do so by submitting a truncation of his true preferences." (See Roth and Peranson, 1999, p. 762, referring to results by Roth and Vande Vate, 1991.) Thus, even if applicants strategically truncate their lists submitted in U, the correct rank order of the remaining choices is preserved. And since truncations are the manipulations that require the least information about others' preferences, they are more likely to occur than other manipulations (see Roth and Rothblum, 1999).

Second, if preferences of universities are perfectly correlated (which they are if universities rank applicants only by their final grades from school), then there is only one stable matching.[27] And if there is only one stable matching, it is achieved by both the college- and the student-proposing Gale-Shapley mechanism. Since the latter is strategy-proof (see Roth, 1982), it then follows that truth-telling is also a dominant strategy in the college-proposing Gale-Shapley mechanism. Thus, we can conclude that the incentives to misrepresent one's preferences in procedure U are null for perfectly correlated preferences and they are very small if the preferences of universities are strongly correlated, as is the case in the German university admission system.

Therefore, we will take the lists submitted in procedure U as the true lists if they are not truncated. If they are truncated, this may be due to either strategic truncations or to the pre-selection procedure. To partly correct for "involuntary" truncations at the pre-selection stage, we proceed as follows. When an applicant has ranked a university first in procedure A that does not appear on the list in procedure U, we put this university first on the list for the true preferences (and

[27] To see this, note that in any stable matching the student ranked highest by the universities gets his preferred matching. Thus, there is only one stable matching for the student with the best final grade. This argument can be repeated for all other students.

append the choices made in U thereafter).[28] Arguably, an applicant should always submit her true first choice in procedure A because, if selected, she has an excellent final grade and therefore a very good chance to be admitted. As a robustness check, we also ran simulations without augmenting the preference lists submitted in procedure U and find our results qualitatively unchanged.

We use the inferred true preferences to compare the matching outcome of the following five scenarios:

(1) Current mechanism used by the clearinghouse with applicants submitting their stated preferences (as recorded in our data).
(2) Current mechanism used by the clearinghouse with applicants submitting their (inferred) true preferences.
(3) Current mechanism used by the clearinghouse with applicants submitting their (inferred) true preferences but truncating their lists in procedure A after the first choice.
(4) Free choice of applicants selected in procedure A plus Gale-Shapley mechanism to distribute the remaining seats among non-selected applicants.
(5) All seats are allocated through a single procedure using the Gale-Shapley mechanism.

The first three scenarios are based on the mechanism that is currently used by the clearinghouse, and we evaluate different strategies under this mechanism. Scenarios (4) and (5) consider alternative mechanisms. Scenario (4) simply allows the selected excellent students to take up a seat at their most preferred university. Remaining seats are then distributed among non-selected applicants through procedure U. Finally, in scenario (5) we replace the existing sequential mechanism by a single (college- or student-proposing) Gale-Shapley algorithm.

We start by considering only those applicants for which the above changes should matter the most, namely applicants who have been selected in procedure A. Table 9 displays the percentage of (selected) applicants receiving their first or a lower preference under different mechanisms. Columns two to four document the results for the mechanism that is currently used by the clearinghouse. Comparing the second and the third column shows that submitting the true instead of the stated preferences increases the percentage of applicants who receive their first choice by 0.8 percentage points.

[28] The first preference in procedure A was moved to the first position of the list submitted in A for 3.81% of the applicants selected in procedure A and for 3.64% of all applicants. Note that we did not use the second and third choices in procedure A for the construction of the true preferences: They might already be strategic since it is suboptimal to list over-demanded universities on lower ranks.

There are two reasons for some applicants being better off when submitting their true preferences. First, the Boston mechanism leads to an efficient matching when all applicants submit their true preferences (see Ergin and Sönmez, 2006) and truth-telling behavior can thus avoid some inefficient matches. Second, over-demanded universities are listed more often on lower ranks when applicants submit their true preferences (see Section 5.1 where we have shown that a number of applicants avoid ranking over-demanded universities on lower ranks). This increases the probability to remain unmatched in procedure A, which in turn can be beneficial for an applicant who has a good chance to receive her first choice in procedure U.

Table 9: Simulation results – Preferences received by applicants selected in procedure A (fraction), by mechanism and preferences

Mechanism	Procedure A + Gale-Shapley mechanism			Free Choice of selected applicants + Gale-Shapley mechanism	Gale-Shapley mechanism
Applicants submit their...	...stated preferences	…true preferences	…true preferences but truncate list in A after first choice	…true preferences	…true preferences
1st preference	.795	.803	.968	.999	.968
2nd preference	.096	.098	.022	.000	.022
3rd preference	.038	.036	.004	.000	.004
4th preference	.021	.025	.000	.000	.000
5th preference	.021	.027	.000	.000	.000
6th preference	.010	.010	.000	.000	.000
Unassigned	.019	.002	.006	.001	.006

The preferences allocated by each mechanism are always compared to the true preferences of each applicant.
For the mechanism "Procedure A + college-proposing Gale-Shapley mechanism" the category unassigned also contains those applicants who could have been matched but not to a university that is among their first six true preferences.
The total sample consists of the 3,266 applicants who have been selected in procedure A.

A much larger increase in the number of students being admitted to their true first choice can be observed when moving to a mechanism in which we truncate the applicants' lists in procedure A after the first choice (Table 9, fourth column). A significant proportion of applicants selected in procedure A thus fail to understand that they should truncate their preference list in procedure A in order to avoid being matched too early to a university they rank low. Too few truncations then lead to unstable matchings as blocking pairs of students and universities exist. The number of selected applicants receiving their first choice would have increased by 17.3 percentage points if applicants had submitted a truncated list in A containing only their first choices.[29] The same percentage of matches to first choices is achieved with a one-step procedure consisting of a student- or college-proposing Gale-Shapley mechanism, reported in the last column of the table.[30]

Not surprisingly, the highest proportion of selected applicants matched to their first choice is reached in a mechanism where universities do not have a fixed proportion of seats reserved for students selected in procedure A, but admit all students in procedure A who list them first (up to their capacity constraint). As the capacity of universities is sufficient to accept all excellent students who list the university first in our data set, this means that the 20% best applicants selected in procedure A can freely choose which university to attend. Therefore, all students selected in procedure A are matched to their first choice if they submit a list in procedure A, a result reported in the fifth column of Table 9.[31]

Up to now, we have focused our comparison of the mechanisms on the overall proportion of applicants selected in procedure A who have received their first choice. But in order to evaluate the efficiency of the mechanisms, one also has to consider people who are negatively affected by the choice of a certain mechanism over another. The proportion of selected applicants who are better off compared to the proportion of selected applicants who are worse off is reported in Table 10. In square brackets, we also report the fraction of *all* applicants affected positively or negatively.

[29] Of course, our assumption that preferences of universities are perfectly correlated with grade might overestimate the probability of a student selected in procedure A getting a seat in procedure U. However, (i) rankings by universities are highly correlated with grade in reality, since by legal restraint universities have to put a large weight on the average grade as an admission criteria. Moreover, (ii) the effect of interviews and tests etc. on the rank-order list of the universities should be zero in expectations.

[30] The equality of the columns relating to the truncated lists and the Gale-Shapley mechanism is no coincidence. The first choice in procedure A is the same as the first choice in procedure U as we use the true preferences for the simulations of both mechanisms. The probability to be matched to one's first choice in procedure A + Gale-Shapley or in Gale-Shapley alone is the same, which is due to the fact that in our data set a university that cannot accept all selected applicants listing it first in procedure A accepts them in the Gale-Shapley part. Note also that the mechanism proposed by Westkamp (2009) results in the same matching as the Gale-Shapley mechanism in our simulations because all universities rank applicants according to their final grades – and thus have perfectly correlated preferences.

[31] Note that the difference between the last two columns has to do with the fact that the selected applicants in procedure A are not necessarily those with the best grades. This is due to the quotas for the federal states which correct for the differences of the grade distributions across states. In procedure U, universities do not use such corrections but take the grade at face value. For a critique see Braun and Dwenger (2009).

Table 10: Simulation results – Fraction of applicants selected in A that are better/worse off by the respective re-design of the assignment procedure, all applicants in brackets

		Mechanism introduced:			
		Procedure A + Gale-Shapley mechanism		Free choice by selected applicants + Gale-Shapley mechanism	Gale-Shapley mechanism
Mechanism replaced:	Applicants submit their...	…true preferences	…true preferences but truncate their list in A after the first choice	…true preferences	…true preferences
Procedure A + Gale-Shapley mechanism	… stated preferences	.077 / .061 [.008 / .007]	.193 / .015 [.013 / .027]	.205 / .000 [.026 / .017]	.193 / .015 [.024 / .014]
	... true preferences	-	.183 / .011 [.009 / .025]	.197 / .000 [.024 / .016]	.183 / .011 [.023 / .013]
	… true preferences but truncate their list in A after the first choice	-	-	.032 / .000 [.027 / .004]	.000 / .000 [.024 / .000]
Free choice by selected applicants + Gale-Shapley mechanism	… true preferences	-	-	-	.000 / .032 [.009 / .008]

An applicant is made better off by the respective re-design if she either receives a seat at a higher ranked university or receives a seat at any university she ranked while remaining unassigned under the alternative mechanism.
The total sample consists of 63,674 applicants, of which 3,266 have been selected in procedure A. Values for all applicants are given in square brackets.

When applicants refrain from acting strategically and submit their true preferences with the existing mechanism remaining in place, a fraction of applicants is better off whereas a fraction of almost the same size is worse off (with 7.7% of the selected applicants better off and 6.1% worse off; 0.8% of all applicants better off and 0.7% worse off).[32] Several effects are at work here and must be considered to explain this finding. On the one hand, the Boston

[32] These numbers seem relatively small, but given that 75% of the applicants are not admitted to any university, the percentage of admitted students who are affected is considerable.

mechanism produces a Pareto efficient outcome when all applicants submit their true preferences. Further, we have already argued that not listing over-demanded universities at lower ranks is optimal within procedure A but can be counter-productive in the overall mechanism, as it may lead to an early match that is inferior to what applicants could have received by moving on to procedure U. Applicants not stating over-demanded universities on lower ranks of their preference list might hence be better off with their true preferences if over-demanded universities on lower ranks of their true preference lists prevent them from being matched too early. On the other hand, some applicants are harmed by replacing the stated by the true preferences. They truncated their lists in procedure A, and by submitting their true preferences (consisting of six universities), they are matched too early and made worse off.

If applicants truncate their true preferences after the first university instead of submitting their stated preferences, the number of applicants affected increases notably. Almost 20% of the selected applicants benefit from the truncation strategy while only 1.5% lose. The truncation strategy of selected applicants goes at the expense of non-selected applicants, since unmatched selected applicants are added to the pool of prospective students competing for the (constant) number of seats available in procedure U (remember that seats not allocated in procedure A are moved to procedure W). Overall, 2.7% of all applicants are worse off while only 1.3% benefit. These results are qualitatively unchanged when we compare the truncation strategy to the scenario where applicants submit their true preferences.

Allowing all applicants selected in procedure A to pick their most preferred university clearly benefits all selected applicants and harms none of them. For the non-selected students, some are better off and some worse, due to the changed set of seats allocated in procedure A and the changed set of students participating in procedure U. Since in contrast to the existing mechanism no seats are moved to procedure W, the number of beneficiaries of the redesign outnumber the losers not only among selected but also among all applicants.

Finally, selected students could also be made better off on average by replacing the existing mechanism by a simple one-stage procedure with seats being allocated through the Gale-Shapley mechanism of procedure U alone. The fraction of all applicants that are better off under such a re-design of the mechanism again exceeds the number of those who are worse off. Compared to the “truncation scenario” both proposals for a re-design of the existing mechanism (i.e., scenarios (4) and (5)) have the advantage that no seats are “lost” to procedure W.

Regarding stability of the matchings from the simulations, some straightforward conclusions can be drawn. Due to the perfectly correlated preferences of universities, the one-step Gale-Shapley mechanism produces the unique stable matching. All other matchings must therefore be unstable. We have already discussed that in the current mechanism, an unstable matching results because many excellent students do not truncate their lists in procedure A. But even if all students played a truncation strategy or the mechanism was re-designed along the lines of scenario (4), the resulting matching would not be stable.

The simulations shed new light on the findings of the empirical tests reported in the previous section. In particular, we can quantify the effects of strategic choices in procedure A with respect to over-demanded universities and truncations (Hypotheses 1 and 3). It emerges that strategic re-orderings of the lists submitted in procedure A benefit some applicants at the expense of others. Most importantly, we show that far too few applicants truncate their lists in procedure A. As a consequence, procedure A – which is designed to give excellent applicants a better chance than others to be admitted to their preferred university – has exactly the opposite effect. Removing procedure A altogether, or softening the quotas in A so that all excellent applicants can be admitted to their first choice, clearly improves the outcome for them.

7 Policy Implications: Changing the Mechanism?

Building on the results reported in the previous two sections, we now briefly discuss ways to re-organize the market for university admissions in Germany.

We have shown that the sequential structure of the three procedures and the use of the Boston mechanism create incentives for strategic behavior, which can be tracked in the data. A mechanism where the quotas for excellent applicants are relaxed, i.e., where all selected applicants get their first choice, makes many applicants better off than before, but it also makes a number of other applicants worse off. Thus, there is no Pareto improvement. Nevertheless, a change in the mechanism might still be considered, especially if excellent applicants are to be given an advantage in the admissions process. An even simpler way to reform the current mechanism is to drop procedure A and move all its seats to procedure U.[33] The simulations show that this has almost the same positive effect on top-grade applicants as giving them the free choice of a university while harming fewer of the other applicants.

In the simulations, we made the simplifying assumption that all universities have the same preferences over applicants. Therefore, the college-proposing and the student-proposing Gale-Shapley mechanism lead to the same

[33] This has also been suggested by the Wissenschaftsrat (the German Council of Science and Humanities, 2004) in a statement highlighting the important role of the final grade as a predictor of academic success. After mentioning the possibility of allocating a number of slots directly to those with the best final grades (as in procedure A), it is explicitly mentioned that a combined procedure where the final grade plays a dominant role might be especially effective (p. 48).

matching. But this is not the case in general as preferences of universities are not perfectly correlated. Thus, students can improve their matching by submitting strategic rank-order lists in procedure U. We therefore propose replacing the college-proposing Gale-Shapley and the Boston mechanism with the student-proposing mechanism, for which truth-telling is the dominant strategy of applicants.

Strategy proofness has the advantage that the amount of information applicants have does not matter for the matching outcome. Thereby, the student-proposing matching algorithm levels the playing field for all applicants. This has already been shown in computational experiments by Roth and Peranson (1999), who analyzed the effects of switching from a program-proposing to an applicant-proposing Gale-Shapley algorithm in the context of the national match for doctors in the U.S.[34]

Importantly, the sequential application of several matching algorithms affects and complicates their strategic properties. A one-stage procedure is therefore preferable. But how can the student-proposing Gale-Shapley mechanism be adapted to the requirement that quotas for excellent students and for students with long waiting times should be met? The Gale-Shapley mechanism requires a consolidated preference list of all participants on both sides of the market. This is simple for the applicants. If strategic behavior does not pay out, applicants do not suffer from having to submit one single list containing their true preferences (instead of three lists as in the current mechanism). A single preference ordering for every university, however, is more difficult to realize as the quotas for excellent students and for students with long waiting times must be accommodated.

Westkamp (2009) has developed a mechanism for centralized university admissions that is based on the student-proposing deferred-acceptance algorithm, but which allows for the quotas of the present system. This mechanism has several desirable properties such as being strategy-proof for the students and stable.

Alternatively, the Gale-Shapley mechanism can be adjusted to affirmative action rules in the college admissions problem or, equivalently, to controlled choice in the school choice problem (see Abdulkadiroglu, 2005; Abdulkadiroglu and Sönmez, 2003). With affirmative action rules, students have to be divided into different types with each student belonging to only one of the types. Each university may have its own quotas, or there can be a quota that applies to all universities. It is then assumed that each university prefers a set of students that

[34] The effects found by Roth and Peranson (1999) are small both for applicants and programs due to the limited number of interviews of each applicant and program and the resulting small set of stable matchings. Although German universities rank students whom they have not interviewed, the set of stable matchings may nevertheless be small due to a strong correlation of the universities' preferences.

satisfies the quota to a set of students that does not satisfy the quota. Again, this mechanism is strategy-proof for the students and stable if preferences of universities satisfy certain regularity conditions.

8 Concluding Remarks

We have provided an empirical analysis of the centralized university admission procedure for medicine and related subjects in Germany. The mechanism, which consists of three procedures that are applied sequentially, is not strategy-proof and applicants have an incentive to misrepresent their preferences. Using a comprehensive data set, we have evidence that some, but not all, students understand the mechanism perfectly well and therefore behave strategically when submitting their preference lists.

Simulations allow us to evaluate the effects of the applicants' choices on the efficiency and stability of the matching and to investigate alternative mechanisms. As many excellent applicants fail to understand the strategic properties of the mechanism, the very procedure that is designed to help them actually lowers their success probabilities. To benefit the excellent applicants, all it would take are some simple changes to the current mechanism.

Our paper not only studies aspects of the current German system, but also makes a methodological contribution. Based on data from a centralized university admissions system, testable hypotheses are developed to assess the functioning of the matching mechanism. Given that the clearinghouse employs the college-proposing Gale-Shapley algorithm in an environment with highly correlated preferences of universities, we can approximate an applicant's true rank-order list and study the efficiency and stability of various mechanisms. In light of the growing importance of school choice and competition between universities, empirical investigations of such markets are an important instrument for evaluating their functioning.

Appendix

Example 1

Assume that there are four universities $U=\{u_1,u_2,u_3,u_4\}$ where $n=\{1,1,2,1\}$ is the respective number of available seats. Every university u gives priority to applicants who rank university u higher over applicants ranking it lower. Furthermore, universities use grade averages to break the ties among students who have given it the same rank. The set of selected applicants consists of $A=\{a_1,a_2,a_3,a_4,a_5\}$ and their respective average grades are denoted by g. To simplify, let us assume that students are allowed to rank no more than three universities. Applicants state the following preferences:

$P(a_1)=u_2;...$	$g(a_1)=1.3$
$P(a_2)=u_1;...$	$g(a_2)=1.0$
$P(a_3)=u_1;u_2;u_3$	$g(a_3)=1.2$
$P(a_4)=u_2;u_3;...$	$g(a_4)=1.4$
$P(a_5)=u_1;u_2;u_3$	$g(a_5)=1.1$

Step 1: In step 1 only the first preference of the applicants is considered. Applicant a_2 is assigned to university u_1. Applicant a_1 receives an offer from university u_2. Applicants a_3, a_4 and a_5 cannot be admitted in the first step.

Step 2: As applicants a_3, a_4 and a_5 are still unassigned, their second preference is considered. While applicant a_4 can be admitted to university u_3, applicants a_3 and a_5 are still left without an offer after round 2: all seats have already been taken at their second preferred university (u_2).

Step 3: Applicants a_3 and a_5 are still unassigned and hence their third preference is considered. Applicant a_5 can be admitted to university u_3. Applicant a_3, by contrast, cannot be admitted. He remains unassigned even though there is one seat left at university u_4.

The algorithm does not eliminate **justified envy** in that applicant a_3 prefers to be admitted to university u_2 instead of remaining unassigned, and university u_2 prefers a_3 over applicant a_1 whom it has admitted (as a_3 has the better grade). In this example it is clear that applicants have an incentive to misrepresent their preferences. Applicant a_3, for instance, could have been assigned to her second preferred university by changing her stated ranking. She could have secured herself a seat at university u_2 by ranking it first. Thus, the algorithm in procedure A is not strategy-proof.

Example 2
(adapted from an example by Ergin and Sönmez, 2006).

For a given subject (e.g., medicine), there are three universities, X, Y, and Z. Each of them has 100 slots and 100 students in its vicinity for which the university is the closest university offering medicine. Assume that the criterion "proximity of a university to the parents' house" becomes decisive. Suppose further that university Z is the least preferred university from the perspective of all students and in every area 50 students prefer university X over Y and 50 students prefer university Y over X.

Now consider a student who lives in the vicinity of university X but who prefers Y over X. If she lists Y first on her list, she loses priority at X. Thus, if she does not get a seat at university Y, it will be difficult to get a seat at X, and she will possibly end up at Z. The safe strategy in this situation is to rank X first where the student has priority. Notice that the more students from area Y rank university Y first, the more advisable it becomes for the student living in the area of X not to list Y first, but to make the safe choice of X. It is therefore an equilibrium for every student to list her home university first. In this equilibrium, every student is assigned to her home university. But it is possible to allocate all students living in the vicinity of university X or Y to their first choice. Thus, all students who prefer university X but live in the area of Y could be offered a seat at X, and conversely, all students who prefer university Y but live in area X could be offered a seat at Y. This allocation Pareto-dominates the allocation under which every student is assigned to her home university.

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