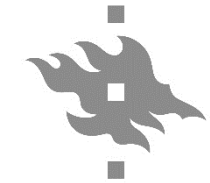

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COLLEGE ADMISSIONS AS A MARKET DESIGN PROBLEM

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Tiivistelmä

Opiskelijavalintojen suunnittelu on herättänyt Suomessa paljon keskustelua, kun viimeaikaiset poliittiset päätökset ovat muuttaneet valintajärjestelmää keskitetympään suuntaan. Jotkut antaisivat korkeakoulujen itse päättää opiskelijavalinnoistaan, kun taas toiset uskovat keskitetyn ja ylioppilastutkinnon arvosanoja hyödyntävän valintajärjestelmän olevan entistä, hajautettua järjestelmää kustannustehokkaampi.

Tarkastellen sekä keskitettyjen että hajautettujen pariutumismarkkinoiden teoriaa että myös kouluvalintoja ja pääsykokeita koskevaa empiiristä kirjallisuutta, tämä tutkielma pyrkii kuvaamaan niitä lukuisia tekijöitä, joita politiikantekijän täytyy huomioida opiskelijavalintoja kehittäessä. Todellisten mekanismien suunnitteluun hyvin soveltuvana kaksisuuntaisten pariutumismarkkinoiden kirjallisuuteen perehdytään syvällisesti.

Niin sanottu student-proposing deferred acceptance –algoritmi osoittautuu parhaaksi valinnaksi, jos politiikantekijä kokee erityisen tärkeäksi, että mekanismi kannustaa hakijoita totuudenpuhumiseen, ja toisaalta valintakriteerinä käytettävää pisteytystä noudatetaan. Näin ainakin, jos korkeakoulujen ei uskota manipuloivan mekanismia. Käytännön mekanismit kuitenkin usein jättävät hakijoille joitain kannustimia raportoida todellisista eroavia preferensseja, hakijat saattavat raportoida epätosia preferensseja itselleen epäedullisesti, ja student-proposing deferred acceptance –algoritmissakin kaikkien mahdollisten hakukohteiden asettaminen preferenssijärjestykseen on vain heikosti dominanttia. Siksi ilmoitettuja preferenssejä ei tulisi ajatella suoraksi todistusaineistoksi hakijoiden preferensseistä.

Korkeakouluille yhteiset pääsykokeet ylioppilastutkinnon muodossa voivat olla hajautettua järjestelmää kustannustehokkaampia, kun korkeakoulujen ei tarvitse kuluttaa resursseja erillisten pääsykokeiden järjestämiseen. Opiskelijoilla on kuitenkin sitten korkeammat kannustimet menestyä ylioppilaskokeissa, ja on jo näyttöä siitä, että ylioppilastutkinnon arvosanoja pyritään korottamaan entistä enemmän. Kokonaisvaikutus kustannuksiin jää siis epävarmaksi empiiriseksi kysymykseksi. Valmennuskurssien tärkeys vähentynee, mikä säästää yhteiskunnan resursseja ja lisää sosioekonomista tasa-arvoa. Toisaalta aikaisemmin elämässä tehtyjen valintojen merkitys korostuu, mikä saattaa heikentää sosioekonomista tasa-arvoa.

Ylioppilastutkinnon tärkeyden korostuminen parantaa kannustimia ahkeraan opiskeluun jo lukio-opintojen aikana, minkä politiikantekijä voi nähdä hyödylliseksi. Vaikka yhteisiin pääsykokeisiin perustuva valintajärjestelmä parantaa huomattavasti opiskelijan mahdollisuuksia tulla valituksi toissijaiseen hakukohteeseen tultuaan hylätyksi ensisijaisesta hakukohteesta, jää empiiriseksi kysymykseksi, kuinka paljolti tämä vähentää uudelleenhakemista kilpailtuihin opiskelupaikkoihin. Tiettyihin korkeakouluihin kohdistuva ylikysyntä on suora seuraus hakijoiden preferensseistä, eikä ratkaistavissa millään mekanismilla, mikä antaa korkean arvon hakijoiden preferenssien tyydyttämiselle.

Avainsanat
Opiskelijavalinnat
Pääsykokeet
Markkinasuunnittelu
Mekanismin suunnittelu

Ohjaaja
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Abstract

The design of college admissions has been a heatedly discussed topic in Finland, as recent government initiatives have led to a more centralized system. Some argue for letting colleges decide on their admissions procedures, while others believe that a centralized matchmaking procedure with priorities determined by the matriculation examination would be more cost-effective.

This thesis aims to characterize various factors that the policy maker must take into account when designing a college admissions procedure, in light of existing theoretical research on both centralized and decentralized matching markets and empirical studies on social determinants of college choice and the capacity of entrance examinations to elicit information on student ability and motivation. The two-sided matching literature is discussed extensively because of its usefulness for designing centralized clearinghouses for matching markets.

The student-proposing deferred acceptance algorithm emerges as the best choice for a policy maker who regards strategy-proofness and respecting of priorities as especially important, at least if manipulation by colleges is implausible. However, strategy-proofness is fragile in practical applications, applicants may try to manipulate also strategy-proof mechanisms and reporting the whole preference relation is still only weakly dominant. Consequently, satisfaction of reported preferences should not be taken as evidence of welfare properties of a matching without qualifications.

The use of a common entrance examination may be more cost effective than a system based on college-specific entrance examinations, as colleges do not then need to spend resources on organizing the examinations. However, students have then stronger incentives to perform in the common entrance examination, and there is already evidence that more students retake the matriculation examination in Finland. The overall effect on the costs of organizing entrance examinations is an uncertain empirical matter. The importance of preparation courses is likely to decrease, which saves resources and contributes to socioeconomic equity. On the other hand, making students choose on their study paths earlier in life may erode socioeconomic equity.

A larger role for the matriculation examination provides stronger incentives for showing effort in high school, which the policy maker may see as beneficial. While a system with a common entrance examination makes it possible for a student to get admitted to a second preference when she is rejected by her first preference, it remains an empirical question to what extent this reduces the propensity to apply again to competitive colleges. The excess demand for certain colleges is a result of student preferences and is not solvable by any mechanism that gives a strong priority to satisfying student preferences.

Keywords
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CONTENTS

1 INTRODUCTION

The optimal way of assigning applicants to colleges has gained much attention in Finland in recent years, both in academia and among political decision makers. The design of college admissions procedures vary a lot between countries. In some countries, such as the United States, universities are to a large extent independent from the state, both financially and in decision making, and the admissions procedure is largely decentralized, with each university making its own optimal admission decision. In other countries, such as Turkey and Germany, universities are more closely connected to the state, and the admissions procedure is run through a centralized clearinghouse. Finland has been traditionally a somewhat mixed case, with the universities largely financed by the state, but the admissions procedure being decentralized[1].

However, the state has pushed for a gradual transition towards a more centralized admissions system, first in the form of a centralized application procedure and recently by a more uniform and less costly admissions criteria. At the same time as the proportion of working age population relative to children and pensioners is dwindling, new high school graduates find it increasingly difficult to get admitted to higher education (Kalenius, 2018; OKM[2], 2016), which is likely to further deteriorate the financial situation of the public sector in the future. In addition to generally increasing the average age of labor force entry, is also feared that many of those not able to continue their studies in higher education soon after graduation from high school face a significant risk of social exclusion (Ahola, Asplund & Vanhala, 2018). The programme of the government of Prime Minister Sipilä stressed the need to hasten the transitions from upper-secondary schools to universities and from university education to working life, and the government saw reforming of the college admissions system as an important way of reducing the gap years between upper-secondary and university education (VNK[3], 2015, 2017).

Colleges, especially those in high demand, have tended to employ demanding entrance examinations as the principal admissions criterion, with generally some but lesser weighting put on the grades of the standardized matriculation examination conducted by

[1] As a curious fact, college admissions were decentralized in the Soviet Union (Hafalir, Hakimov, Kübler & Kurino, 2018).
[2] OKM stands for the Ministry of Education and Culture.
[3] VNK stands for the Prime Minister's Office.

high school graduates. Pekkarinen and Sarvimäki (2016) proposed that the college admissions procedure should be mainly based on the grades of the matriculation examination, with entrance examinations mostly discarded because of their high costs. Reports commissioned by the Finnish ministry of education and culture concurred with these recommendations (OKM, 2016, 2017) and universities are currently in a process of transition towards a system with much less role for entrance examinations.

The practicalities of college admissions provide also lessons for economists. College admissions is one example of matching problems that play a large role in the blossoming literature and practice of market design, which Roth (2018) defines as a field of economics that tries to ”understand how the design of marketplaces influences the functioning of markets”. Budish (2012) distinguishes matching problems from theoretical mechanism design by noting that while in the mechanism design literature the conventional objective is to find a mechanism that maximizes social welfare subject to technological and incentive constraints, in the matching literature, the goal is usually the more practical one of finding a mechanism (i.e. a matching procedure) that satisfies a number of properties seen as desirable by policy makers, such as efficiency and fairness. Roth (2018) also notes that in mechanism design, the policy maker is often assumed to have a complete freedom to install new mechanisms through which the economic agents have to operate, while the market design literature must, as more practice-orientated, to accept that real-life participants often have a lot of freedom to act outside of the marketplace, and consequently the designer of the marketplace cannot hope to have a complete control over the strategy-space of the participants.

Matching markets are pervasive in modern societies and come in many forms. Aside from those allocating students to schools and colleges, matching markets include those for labor, marriage, housing and even organs. One exciting aspect of them is how they bring to the forefront issues of centralization versus decentralization both in decision making and marketplaces. Roth (1984) and Roth and Xing (1994) detail how decentralized matching markets can often be prone to unraveling, and how commitment to dealing via a centralized marketplace led in some cases to a more stable procedure[4].

[4] Even the ancient Greeks were no strangers to these questions: in *the Republic*, Plato famously proposed centralizing the marriage market along the lines of the so-called serial dictatorship mechanism, with the

A distinction between two main types of matching markets may be made. In two-sided matching markets, there are two sets of agents, and agents on one side of the market look for agents on the other side of the market to match with. In one-sided matching markets, or priority-based allocation problems, there is a set of agents to whom the policy maker allocates a set of goods. Another important distinction is between markets where transfers between markets participants are not allowed or are otherwise implausible, such as admissions to public schools, and markets for which transfers between participants are paramount, of which probably the most important example is labor markets. The starting point of the game-theoretic analysis of matching markets can be seen to be the seminal work of Gale and Shapley (1962).

The theory of matching markets has found numerous avenues for further research from practical matching problems, usually with the focus on how poorly performing mechanisms could be improved, or on analyzing how a currently decentralized market would work, if a centralized clearing house was installed. Matching theory has even occasionally influenced those applications. The American doctor residency program for new physicians (the National Resident Matching Program, NRMP) uses a mechanism designed in Roth and Peranson (1999) while the authority responsible for the Boston Public Schools decided to change their school choice mechanism, explained in Abdulkadiroğlu et al. (2005), largely because of the empirical evidence of Abdulkadiroğlu et al. (2006) and the experimental results in Chen and Sömnez (2006). Similarly, economists helped to redesign the New York public high school matching mechanism, as documented in Abdulkadiroğlu, Pathak and Roth (2005).

Maybe as the most famous application, the burgeoning literature on organ exchange problems (e.g. Roth, Sönmez & Ünver 2004, 2005, 2007; Ünver, 2010) has helped to launch several kidney exchanges. Abdulkadiroğlu and Sömnez (1998, 1999) and Sönmez and Ünver (2010b) consider the problem of allocating houses to tenants. Sönmez and Ünver (2010a) and Budish and Cantillon (2012) analyze the course allocation problem, in which students are assigned sets of college courses. Sönmez (2013) and Sönmez and

choices made in a serial order formed according to military merit. Though understandable from the viewpoint of encouraging good military performance, the modelling framework of section 3 (and intuition) will make it clear that such a mechanism would fail the requirement of stability, as the prospective spouses are unlikely to view themselves purely as objects to be allocated. Consequently, the mechanism would not be easily implementable.

Switzer (2013) propose improvements to U.S. Army caded-branch matching. As another entry-level labor market application, Dimakopoulos and Heller (2019) analyze the mechanism used in Germany for allocating lawyers to regional courts for trainee-ships. Matching markets with couples on the other side (e.g. Klaus & Klijn, 2005; Kojima, Pathak & Roth, 2013; Roth, 1984), markets with constraints on allocations (Kamado & Kojima, 2015, 2017a, 2017b) and matching with indifferences (e.g. Abdulkadiroğlu, Pathak & Roth, 2009; Abdulkadiroğlu, Che & Yasuda, 2015; Erdil & Ergin, 2008, 2017) provide interesting examples of how issues deemed important in practical applications have spurred substantial research towards more general models.

Various national college admissions mechanisms have also been documented and analyzed in the market design literature. Westkamp (2013) discusses the German, Chen and Kesten (2017) the Chinese, Dur, Pathak, Song and Sömnez (2018) the Taiwanese, Balinski and Sömnez (1999) the Turkish and Aygün and Bó (2017) the Brazilian admissions mechanism. Aygün and Turhan (2017) discuss the mechanism used for admissions to engineering colleges in India and Hassidim, Romm and Shorrer (2017) the admissions to post-graduate studies in psychology in Israel.

For wide-ranging literature reviews on the theory of market design, see Sönmez and Ünver (2011) and Abdulkadiroğlu and Sönmez (2013), and for surveys of existing applications, see Biró (2017) and Kominers, Teytelboym, and Crawford (2017) and specifically Ashlagi (2018) for a review of applications in health care. Roth (2002, 2008a, 2018) offers a non-technical discussion on market design and historical experiences of markets both evolved and designed, and Roth (2015a) presents market design for a general audience. Biró and Klijn (2013) provide a literature review on matching with couples and Pathak (2011, 2017) on school choice applications. Kojima (2017) concentrates specifically on the recent theoretical developments that have been driven by empirical findings. Finally, Chiappori and Salanié (2016) discuss the econometric approaches used to analyze empirically various kinds of matching markets.

Duflo (2017) maintains that economists should pay more attention to details of policy application and the institutional setting, and not just dismiss questions concerning specific applications as trivialities that do not affect the general principles derived from abstract models or as something that officials and policy makers are easily able to work out. On

the contrary, the fine details often determine whether the reform in question achieves the goals set to it at all, and Duflo believes that economists are in many cases well-positioned to work out the policy implementation ("plumbing") in addition to providing the general framework. The issues confronted in the practical implementation of college admissions procedures provide another case study on how the details abstracted away in theoretical models need to be considered in practical market design.

While such issues are easy to sideline in theoretical literature, designers of real college admission mechanisms must also choose between different normative objectives. College admissions procedures confront the usual welfare economic problems of preferences, choices and welfare. However, because choices between different educational paths have so large effects on individual welfare, these questions become even more daunting than in the context of most other goods. It is also clear that admission mechanisms cannot be designed separately from other institutions, but considered in conjunction with questions concerning the autonomy of universities and the optimal high school curriculum.

Lately economics, and the field of market design in particular, has attracted some critical attention from political philosophy (Nussbaum, 2016, Sandel, 2012; Sandel, 2013) for market reasoning creeping into new areas social interaction and economists in general having a limited and unsophisticated approach to welfare evaluations. Though economists tend to be uneasy about engaging in moral reasoning, Atkinson (2009) maintains that economics cannot help dealing with normative theories. Roth (2007) believes that economists should take widely held normative judgements such as repugnance towards organ trade as a given constraint on market design, rather than try to change the public morality. Li (2017b) takes a step further and argues that market designers need to have a position of informed neutrality towards reasonable normative theories, meaning that normative analysis should not rely solely on preference utilitarianism.

This thesis aims to characterize the college admissions problem to understand how the existing economic theory may help in guiding public policy on the issue, and to shed some light on the issues that confront designers who try to apply lessons from theoretical matching models on the practice of matching markets, and what further research is still required. We provide a context for the review by discussing the Finnish college admissions procedure. This may be seen as the plumbing approach to the design of college

admissions procedures. The topic is important because of the large role college admissions play in allocating talent among different subjects and industries in any modern society, and the interest that the general public have in that this allocation is done efficiently and fairly. No such review, incorporating both recent theoretical research and empirical evidence, has been done.

A distinction should be made between two different uses of the term ‘college admissions problem’: above I used it in its wider, more practical sense, while below we will also discuss it as a one kind of a model analyzed in the matching literature. For the sake of readability, we will often call college programs, or college faculties, simply colleges. As a slight abuse of terminology, we often use the terms mechanism and algorithm interchangeably, though mechanism can also be understood to refer more widely to the institutional setting through which the matching takes place, including the algorithm used to calculate the matchings.

The Finnish upper secondary education has a dual structure of separate schools for vocational education and general, academy-oriented education, the latter of which we may call high schools. While also those who have completed vocational studies are eligible for higher education, we will for brevity focus on the college admissions of high school graduates, because high school graduates form an overwhelming majority of applicants to colleges where the number of applicants relative to the student intake is very high.

We start by briefly going through the Finnish institutional setting and the current changes to it in section 2 and outline central theoretical results from the matching market literature relevant for designing a clearinghouse in section 3. Section 4 contains a discussion on the aims of a college admission mechanism and the normative constraints that usually shape such procedures, some consideration on the welfare economics of college admissions and models of decentralized markets. Section 5 concludes.

2 THE INSTITUTIONAL BACKGROUND

This section will first briefly and informally discuss the supply and demand of higher education in Finland, and then the current admissions procedure used and the most important recently implemented changes to it.

2.1 Supply and demand of higher education in Finland

Around 150 000 applicants apply for higher education in Finland annually, but colleges have capacity to grant degree places to only around one-third of them. While the amount of new high school graduates has decreased during the last two decades and currently around one-fourth of them does not apply to college in the year of their graduation, and there are currently around 1.5 times as many degree places available as there are new high school graduates, the proportion of new graduates obtaining a degree place at a college for the next academic year has decreased sharply, from 43% in 2007 to 28% in 2017. (Ahola et al, 2018; Loukkola & Tuononen, 2019). The increase in the proportion of the labor force with a college degree has stalled as a result: a young adult aged 25-34 was less likely to have college degree in 2016 than in 1998, meaning that concerning the proportion of young adults who have completed a degree in higher education, Finland is starting to sink under the average in OECD countries (Kalenius, 2018).

2.1.1 Demand of higher education

The proportion of new high school graduates not applying for college has actually slowly decreased (Ahola et al, 2018), so the statistical probability of a new high school graduate obtaining a degree place for the next academic year has decreased significantly. In principle, this could signify not so much increasing difficulties in getting admitted but a decreasing willingness to continue studies the same year and therefore heavily invest in passing an entrance examination, and an increasing willingness to take gap years, possibly to gain some work experience and decide on the choice of education. In fact, TAT (2018) report that the proportion of new high school graduates planning to take a gap year has increased by half from 20% in 2014 to 30% in 2018, and 28% of third year high school students are still uncertain of their higher education application choices. However, causal relations are difficult to determine, because the increasing propensity to take gap years could be the result of either decreasing willingness to continue studies straightaway or an

understanding of the fact that getting admitted to a popular college program has gotten increasingly difficult, and getting admitted could take several attempts.

In any case, a central reason for the decreasing admittance rates seems to be that the demand for degree places has at the same time been steadily increasing: while approximately 110 000 applied to higher education in 2000, the number has climbed by 40 000 within two decades. On top of the new high school graduates, many of the graduates of recent years that have not yet applied or succeeded to get admitted apply again, many of the recent graduates that previously accepted a degree place apply to some other college program, maybe because they need multiple attempts to gain a place at one of their more preferred colleges and spend the meantime enrolled in a less preferred program. They may also apply again because their preferences have evolved, and even some who have already completed a degree apply again, probably largely for the same reasons and because of labor market conditions. The number of foreign students in Finnish colleges has also increased over time. On the other hand, the number of Finnish high school graduates looking for education abroad has increased. (Ahola et al, 2018).

In 2016, 27% of college applicants had a previous higher education degree or a degree place (Karin-Oka, 2017), while new high school graduates constituted a similar proportion, around one-fourth of all applicants (Ahola et al, 2018). Ahola et al. conclude that new high school graduates are not underrepresented as a fraction of admitted students. On the contrary, they find that on average, new high school graduates have a higher statistical probability of getting admitted compared to other groups. However, it is clear that those switching between programs or looking for another degree have contributed significantly to the present situation where a large proportion of the new high school graduates do not get admitted.

There is also a wide dispersion in the demand that different college programs face: degree places medicine and law are highly contested, while some, such as natural sciences and mathematics, find it difficult to fill their seats (Ahola et al, 2018). For example, only around 4% of applicants got admitted to medical school and around 5% to law school in 2018 (Studentum, 2019). Of applicants looking for a degree place in medicine, 40% already had a college degree or a degree place in some other program (Karin-Oka, 2017), highlighting the fact that some applicants are willing to use considerable periods of their

lives pursuing their preferred education. The eagerness of new high school graduates to study in a university has increased, while the attraction to continue in a university of applied sciences has decreased (TAT, 2018), which might point to the direction that young people are increasingly planning on applying to programs in high demand.

2.1.2 Supply of higher education

Historically, it has been seen important to maintain the independence of universities from the state, and according to the law (Universities Act 558/2009, Universities of Applied Sciences Act 932/2014), universities have a wide autonomy in deciding on their student intake and the curriculum. However, universities are largely financed by the state, and the supply of higher education is largely determined in negotiations between the universities and the state, where the targeted number of finished degrees is specified for different study sectors. The universities then decide on the number of their degree places based on the degree targets and other factors, while state aid encourages them to meet the targets but not to exceed them (the universities are paid per degrees finished up to the target number). (OKM, 2016).

As discussed most recently in OKM (2015), the targeted numbers of degrees are decided based on the expected demand for different kinds of labor and the targeted industrial structure. The estimation process is done approximately every four years, usually once per an electoral term of the parliament (Kalenius & Karhunen, 2018). The currently used estimate of the labor demand is computed by Ahokas et al. (2015). The results are regularly criticized as inadequate. For example, Karhunen (2019) recommends generally increasing the supply of degree places, and Kotamäki (2019) specifically recommends increasing the intake of medical schools.

Kalenius and Karhunen (2018) criticize the supply determination process as opaque and report that while the estimates of the future demand for labor with vocational education and the demand for highly educated labor have fluctuated, the relative share of estimated demand for highly educated labor has gone down during the last two decades. While the policy makers like to announce targets of higher shares of highly educated labor, they have often at the same time contracted the supply of higher education. For example, the government of Prime Minister Katainen reported to target the Finnish labor force to be

one of the most highly educated among the OECD countries by 2020 (VNK, 2011), but ended up reducing degree places in higher education (OKM, 2012b), as recommended in OKM (2011). The increase in the share of labor force with a college degree has been meant to be achieved by allocating a larger number of the degree places to those with no prior higher education.

Kalenius and Karhunen (2018) conclude that policy makers have failed miserably in this, and the reductions in the supply of higher education have directly decreased rates of new high school graduates gaining a degree place. Consequently, in addition to the increasing demand for higher education, the growing difficulties new high school graduates encounter in entering higher education also result from policy decisions to decrease the supply of education.

2.2 Recent changes to the Finnish college admissions procedure

Reforming of the higher education system and the admissions procedure has been an objective of several previous governments. Ahola et al. (2018) discuss briefly the recent history of the Finnish college admissions procedure.

Universities have traditionally employed entrance examinations to choose among their applicants. Already in the 1990s, the Ministry of Education commissioned studies (Halonen, 1994; Jussila, 1996) on extending the role of the matriculation examinations in the admissions procedure. It was deemed that the use of matriculation exam grades should be increased in subjects where it is applicable, having separate queues for students applying by admission examinations and those applying based on matriculation examination grades. However, Halonen and Jussila both advocated keeping a central role for admission examinations as a way of both ensuring that an applicant has the requisite skills for finishing her studies successfully and keeping open an alternative route to higher education. The objective of improving the position of new high school graduates was also discussed back then.

Halonen (1994) also argued for a central application procedure which would include all the higher education programs in Finland, but largely due to opposition from universities, the joint college application procedure was established only in 2009, and in 2014 was extended to cover all undergraduate programs taught in Finnish, with some exceptions

(as decreed in 294/2014). In the centralized applications and admissions procedure, all student applications are processed through a centralized electronical marketplace, in which students are asked to present six of their most preferred college programs, colleges report their preference rankings over their applicants and the allocation is then calculated using the student-proposing deferred acceptance algorithm of Gale and Shapley (1962), which will be presented below. The procedure is ran every spring and autumn, but nearly all of the seats are allocated in the procedure that takes place in spring (OKM, 2016).

While the allocation is done centrally, the law states that universities decide on their student admissions procedures, with some restrictions, and it also specifies the conditions that determine eligibility for higher education. Loosely speaking, eligibility for higher education can be achieved by passing the matriculation examination, completing a vocational degree or by having completed a foreign degree, which yields the right for higher education in that country.

However, universities are left a large degree of freedom concerning student intake, as it is also mentioned that "eligibility for studies… may also apply to a person whom the university deems otherwise to have sufficient knowledge and skills for the studies". Universities are allowed to set different admissions requirements for students with different educational backgrounds, but the admissions system must set the same requirements to those of similar educational backgrounds. As the most important example, those who have completed a vocational degree need not be treated in the same way as high school graduates who have passed the matriculation examination.

In practice, colleges have traditionally formulated their preferences over students by heavily employing entrance examinations, with generally some but lesser weighting put on the grades of the matriculation examination. Some college programs, such as pedagogical studies, also utilize interviews. Usually colleges have multiple student queues, of which one is for those applying purely on the basis of the entrance examination points, one is for those applying based on combined points of the entrance and the matriculation examinations and possibly one for those applying purely on the basis of the matriculation examination points. Programs on the same subject located in different universities often coordinate by using the same entrance examination or even by keeping their exams on the same day, to block students from applying to multiple programs.

Another large change implemented in the recent years (in SA 256/2015 and SA 257/2015) is the requirement that colleges need to reserve some proportion of their degree places allocated in the joint application process for first-timers and introduction of a new transfer application system, in which those already in college can apply for switching to a different program. The proportion of seats reserved for first-timers is left for colleges to decide. The reasoning for this reform is given in the government's proposal 244/2014:

1. As more degree places are reserved for first-timers, more of them are selected, hastening the transition from upper-secondary education to higher education.
2. Because accepting a degree place affects the applicant's chances to be accepted in any future joint application process, the applicants are less likely to enroll in programs they do not intend to finish or utilize in the labor markets, and college seats are therefore more likely to be allocated to more motivated students.
3. The excess demand for the degree places allocated in the joint application can be reduced by having a separate system for transfer applications for students that wish to change their major subject. It is admitted that this is unlikely to increase the number of total supply of degree places, but it is contended that the number of redundant rights to study would be reduced, decreasing administrative burden.

Most recently, the government of Prime Minister Sipilä stressed the need for reforming the Finnish college admissions procedure, with the aim of lengthening the average working career by hastening the transition of new high school graduates to higher education (VNK, 2015, 2017). To this end, the government both recommended and financially encouraged universities to abandon costly entrance examinations in favor of an admissions procedure that employs mainly matriculation examination grades (OKM, 2016), and in some sectors of education, colleges now select a much larger proportion of their students based on it (Ahola et al, 2018).

For example, for the joint admissions procedure of spring 2019, business schools select 60% of their students based on the matriculation exam grades, and the rest purely based on an entrance examination. Moreover, business schools reserve all of the seats in the matriculation examination quota for first-timers (Hyvönen, 2019). Similarly, medical schools will select 51% of their students and law schools 40% of their students solely

based on matriculation examination grades from 2020 onwards (Lääketieteelliset.fi, 2018; Oikeustieteelliset.fi, 2019),

While college admissions systems differ across countries, McGarth et al. (2014) note that in Europe, access to higher education is characterized by a reliance on secondary education qualifications as the main requirement for entry into higher education and centralized admissions procedures and decision-making. The belief that higher education is a right is also widespread, and therefore those that have completed the required background education are ensured a place at a college with no tuitions collected. This is manifested most obviously in the open access systems of, for example, Germany and France, where completing a secondary education degree yields immediate admittance to higher education, and the sorting of students to study paths most suitable for their abilities occurs during college studies, not before them.

The recent trend in Finnish universities is also towards larger undergraduate programs, where the students' choices concerning their field of specialization are meant to be confirmed during the studies with the help of student counselling: the hope is that this will reduce the need of switching between college programs and therefore reduce the pressure on the joint application process (OKM, 2016), but there is little evidence on the results so far. In any case, insofar as the most demanded programs, most importantly medicine, law, and business studies, are not seen as practical to be integrated to larger undergraduate programs, this is unlikely to reduce the pressure on them.

In many other countries, most notably in the United States, obtaining a higher education is in comparatively costly (at least in out-of-pocket costs), and both the admissions procedure and the decision-making on the supply of education are decentralized. The increasing centralization, higher utilization of matriculation examinations and larger undergraduate programs then amount to a swift in the Finnish admission procedure towards a more standard European college admissions system, though McGarth et al. (2014) note that the current trend in Europe is to grant more autonomy to universities.

2.3 The use of entrance examinations

The transition from an entrance examination -based admission system towards admissions based on secondary education qualifications has instigated a lot of debate,

which Ahola and Spoof (2018) summarize. We discuss below the rational given for entrance examinations, and the costs caused by them.

2.3.1 The rationale for entrance examinations

Universities have preferences over their students, presumably because they want to train students as suitable as possible for the profession in question, but universities need information on their applicants to rank them. Of course, it is trivially true that there are mechanisms that are better than a weighted combination of the matriculation exam grades in discovering the true capabilities of the students. A college program with its numerous exams provides the college a ranking over its students. It answers the question of how suitable the students are for the studies relative to each other, and insofar as the program is good training for the profession, it also yields information on suitability for working in the profession. A good college program is therefore a good information revelation mechanism by itself, but prohibitively expensive for admissions purposes.

The question is then of whether using some other information discovery mechanism than the matriculation examination grades yields a better tradeoff of information and resources, and how this might differ between subjects. According to OKM (2010, 2016), universities report that they believe entrance examinations to provide information on motivation and suitability of students for the studies in question, and that for many subjects, the high school curriculum does not introduce applicants to the topic in a sufficient manner for the applicants to make an informed choice among the educational possibilities, and that for the same reason, the matriculation exam does not make it possible for colleges to reasonably choose among the applicants. It is also contended that the grading of the matriculation examination does not sufficiently discriminate between students because of the coarseness of grading. Some colleges also report that students that are accepted based on the matriculation examination are less well prepared for the studies than those admitted by entrance examination, because preparing for an entrance examination requires studying the subject (Yle, 2019 June 15).

How much additional information do college-specific entrance examinations provide over the information contained in secondary education qualifications? There is surprisingly little work towards understanding this topic. Ahola and Spoof (2019) review

the literature and find that generally, the correlation between performance in high school and performance in college studies (with respect to course grades) is moderate and larger than the correlation of college performance with success in entrance examinations. Both seem to be weaker in predicting the progression of studies than course performance. Consequently, there is little evidence of entrance examinations yielding more reliable information on student abilities.

However, this question is very difficult to assess empirically. We would need to randomly allocate applicants to a group that must take the entrance examination and a group among which a subgroup of students is selected based on the matriculation examination grades, and then assess the relative performance of these groups in their studies. Difficult questions would still remain, as changes in the admissions system induce changes in the incentives of high school students, therefore affecting the abilities of the pool applicants (the allocation to treatment groups would then need to be done at an earlier stage, possibly at the start of high school studies). The intake of one college also affects the pool of applicants that the other colleges face, leading to unknown general equilibrium effects, which are what the policy maker is really interested in.

Prime Minister Sipilä's reform has also been criticized on the grounds that it confounds the autonomy of the universities (e.g. Hämeen-Anttila 2017; Jalovaara, 2017), implying either that letting universities have a free hand to decide on their admissions criteria is beneficial in terms of the compatibility of colleges and applicants or that autonomy of universities is an important value in itself, possibly trumping other concerns about societal outcomes. Many also believe that entrance examinations are required to give a second chance to students who did not do well in high school (OKM, 2016). When admittance to higher education is determined on the basis of secondary education qualifications, decisions made at the beginning of high school studies affect the probabilities of getting admitted to college, and Hämeen-Anttila believes that high school students are not yet mature enough to make informed choices between different educational paths. He even argues that if the government's aims to reduce the costs of the college admissions system, it should rather seek to abandon matriculation examinations.

Ahola and Spoof (2018) note that while reducing the average number of gap years between high school and higher education has been the main stated aim behind the reform,

the reasoning on how abandoning entrance examinations is going to allocate more seats to new high school graduates is weak. Ahola et al. (2018) comment that allocating seats based on matriculation examination grades will simply assign the sparse degree places to somewhat different students than what a system based on entrance examinations would, with little reason to believe that systematically more will be allocated to new high school graduates. Of course, one way to ensure that an arbitrarily high proportion of degree places will be allocated to new applicants is to set binding quotas to that effect, but universities have so far set the first-timer quotas too low to have much of an effect (Ahola et al, 2018), and there is some anecdotal evidence that giving first-timers a priority has reduced the propensity to accept places in programs other than students' first preference (Yle, 2018 December 21), consequently even slowing the transition to higher education.

Some less popular colleges also report that they organize entrance examinations principally as an yield control tool, as they believe that making application costly weeds out the applicants who apply but do not take up the seat they are offered (OKM, 2016), either because their plans changed in the meantime or they irrationally listed as acceptable a college they do not consider acceptable. There is little research that studies the extent of this phenomenon. In principle, this could be solved revenue-neutrally by making the applicants pay the college a deposit that would be returned with interest in every other case but when an admitted applicant does not take up a seat she is offered.

2.3.1 The costs caused to applicants

Pekkarinen and Sarvimäki (2016) and OKM (2016) discuss the costs of the entrance examinations system. In addition to administrative costs, there are the costs accruing to the applicants. The more competition there is for the seats, the higher is the time investment required from the applicant to have a given probability of getting admitted. This time could be used for working, studying something else or recreation. Assuming quite reasonably that people do not rank studying for an entrance examination very high as an occupation satisfying for its own sake, it entails both a monetary and psychological cost for the applicants.

If it were so that the knowledge gained during the study process were highly generally applicable, yielding benefits for other entrance examinations or in the labor market, the

loss would not be great. However, the material studied for an entrance examination tends to be highly specific to the subject in question and of little use in examinations of other colleges. Because of this, for any two competitive entrance examinations and for nearly any student, studying for both makes it very probable that the student will pass neither. This produces *congestion* in matching markets: market participants cannot gather all the required information on the other side of the market before the market closes. The result is that the assignment is not optimal: some talented students who get rejected by a top college are left unmatched.

In effect, entrance examinations amount to extension of the higher education curriculum outside of colleges, and the knowledge gained studying for entrance examinations then mostly benefits those who get admitted. It is sometimes argued (e.g. Jalovaara, 2017) that studying for a demanding entrance examination yields study skills required in higher education, but it seems unclear why such skills should be learned in the entrance examination phase and not in college, or already in high school. As noted above, universities also state they see entrance examinations as a way of providing information to students on the subject matter to help them choose on their career path, but in the case of the more competitive entrance examinations, seeing if the topic feels interesting at the phase of preparing for the examination is hopelessly late.

Of course, not all entrance examinations are that costly. The less possibilities there are to prepare for the entrance examination, and the more the exam tests general skills, the less costs it is likely to impose on the applicants. Some colleges employ entrance examinations for which very little or none preliminary material is given, where the aim is to test general problem solving skills instead of the ability to learn subject material (OKM, 2016). However, matriculation examinations are similarly meant to test logical thinking and problem solving abilities, and it seems difficult to believe that such entrance examinations could yield much additional information on abilities. As mentioned above, interviews are used in some college programs. While this might not be very costly for the applicants, as interviews are presumably difficult to prepare for very extensively, this still spends some college resources, and the evidence on the ability of the interviewers to select the best among the applicants is weak (see Dana, Dawes & Peterson, 2013; DeVaul et al, 1987; Grove et al. 2000)

Medical schools have recently switched to using entrance examinations based on high school curriculum, which has long been common in technical colleges (OKM, 2016). Similarly, business schools currently allocate 40% of their seats by an entrance examination based on high school material (Hyvönen, 2019), and it therefore seems that the trend is towards less costly entrance examinations. However, this amounts effectively to testing the exact same skills in both the entrance and matriculation examinations, again raising the question of what additional information the colleges seek to gain by using such examinations. Law schools still employ entrance examinations that are based on law school material, likely reflecting their belief that the high school curriculum does not adequately reflect the competencies required for studying law. Arts schools will also continue to admit students based on applicable performances and work samples (OKM, 2016).

Concerning autonomy, it does not seem self-evident that self-seeking behavior by universities (or individual college programs) will result in the best possible compatibility between colleges and applicants on the aggregate level, nor that universities are likely to set admission criteria with eye on the best possible aggregate outcomes. For example, it seems likely to that the faculty staff in a medicine program are hoping to gain the best possible set of students for themselves, though the skill sets possessed by those students would be very useful also in engineering programs.

More importantly, universities do not care about the costs accruing to the students: other things equal, a college will always prefer its new students to be more knowledgeable about the subject. Therefore, even if the matriculation examination grades contained practically all the same information about the candidates' capabilities and suitability for the education as the entrance examination used, the university will prefer to employ the examination (as long as the costs from it do not exceed the benefit from students more acquainted with the topic), having no regard for the costs caused to the vast majority of students who do not get admitted.

Of course, the only colleges likely to find demanding entrance exams on subject material beneficial are those that are in sufficiently high demand. This is because a highly demanded college will not be downgraded in its applicants' preferences when the entrance examination gets more difficult (the cost of entrance examinations is a relatively

small matter for the applicants when they consider their likings over different educational paths) and the applicants are forced to learn the material carefully because of the competition.

On the other hand, if colleges in less demand try to force applicants to study their curriculum in advance for the entrance examination, they are more likely find their applicants learning the material only superficially, either because applicants know that there is not much competition or because the college is not a first preference for them and they therefore cannot afford to use too much time preparing for the exam. This might explain why programs in high demand, especially medical, law and business schools, have tended to employ such entrance examinations, while seats in less demanded colleges, such as engineering schools, have usually been allocated by examinations focused on the high school curriculum or general logical abilities.

2.3.3 Preparation courses

In addition to its costs, the entrance examinations system is often faulted for the preparation course business that it encourages. Ahola et al. (2018) find that taking a preparation course seems to be associated with getting admitted even taking into account various background factors, and those with more educated parents are more likely to take preparation courses.

However, the extent of a causal relation is left uncertain: maybe most importantly, the motivation to get admitted certainly differs between applicants and could increase the likelihood of both attending a preparation course and getting admitted, and Ahola et al (2018) have no obvious variable for controlling motivation (except maybe the reported previous school performance, but it is uncertain how high is the correlation between success in high school and the motivation to get admitted to a specific college program, when secondary education qualifications do not determine entry).

Laukkonen (2018) also finds some evidence that high school graduates from low-income families are less likely to apply to highly selective programs, such as medicine, possibly reflecting lower financial means to enroll in preparation courses and take time off to prepare for the entrance examination. The preparation courses business that the admission examinations system encourages is therefore possibly less than ideal from the point of

view of equality of opportunity in education. However, Ahola et al. (2018) find no evidence of more expensive preparation courses yielding additional advantages over lower priced courses, nor of there being large regional differences in preparation course enrollment.

Ahola et al. (2018) also note that statistically, attending a preparation course seems to generally lessen the expected gap in admittances between those with highly educated parents and those with less educated parents (i.e. applicants from less academic households have benefited more from taking a preparation course), from which they conclude that preparation courses might not confound equality of opportunity quite as much as often feared. However, this does not change the fact that applicants with more educated parents are more likely to attend preparation courses and hence, the existence of these courses contributes to children inheriting their parents' educational level in the aggregate.

The preparation course industry is also an artifact of the entrance examination system in the sense that it exists solely to extract resources from applicants, intensifying the competition for admittance. Of course, if matriculation examinations largely determined admittance to higher education, the preparation course business might switch to offering courses for high school students, and this is indeed something that is currently happening: in addition to preparation courses for matriculation examinations, courses are even offered to students in higher comprehensive school, marketed as helpful to get into well-respected high schools, and there is some anecdotal evidence that this corresponds to an increase in demand (Yle, 2019 April 3).

While this might still present equity issues, at least then the preparation courses would contribute to learning the substance of the high school curriculum, and while there are no publicly funded preparation courses for entrance examinations (based on the subject material), high school itself serves as a preparation course for matriculation examinations. It is not self-evident that more contact teaching in the form of commercial preparation courses will have a very large effect on average, and it must be noted that the preparation course industry has an incentive to maintain the impression that their product is a necessity for leading a successful life. In any event, it does not seem likely that there

exists an admission mechanism that makes the well-off unable to leverage their higher wealth to get some additional preparation.

3 MECHANISMS OF COLLEGE ADMISSIONS

This section starts by presenting the canonical college admissions model in conjunction with the closely related school choice and student admissions models. We discuss the most important and general results obtained for them in the literature and introduce then the more popular matching algorithms. We then proceed to discuss some recent theoretical advances, in particular some large matching market results, and also very briefly empirical work concerning preference estimation.

3.1 The college admissions problem

The mechanism design problem of matching students to schools admits a number of related but distinct approaches. Sönmez and Ünver (2011) make the distinction between the college admissions, student placement and school choice problems, or models.

The traditional college admissions problem, first studied by Gale and Shapley (1962) and Roth (1985), is an example of two-sided matching market, where students look for colleges and colleges look for students. We have

- a finite set of students S
- a finite set of colleges C
- for each college $c \in C$, a capacity q_c,
- for every student $s \in S$, a strict preference relation $\succ_s$ over colleges and remaining unmatched,
- for every college $c \in C$, a strict preference relation $\succ_c$ over groups of students (including singletons) and leaving seats unfilled, with the *responsiveness* property (Roth, 1985):
    1. for all $s, s' \in S$ and $S' \subset S \setminus \{s, s'\}$, $s \cup S' \succ_c s' \cup S'$ if and only if $s \succ_c s'$,
    2. for all $s \in S$ and $S' \subset S \setminus s$, $s \cup S' \succ_c S'$ if and only if $s \succ_c \emptyset$, where the empty set $\emptyset$ denotes remaining unmatched.

As a slight abuse of notation, we make no difference between a singleton set and the only member of it. We often refer to both students and colleges as agents, when there is no

need to make a distinction between the two sides of the market. The preferences are lists of *acceptable* agents on the other side of the market with the most preferred choice listed first, the next best as the second one and so on, with college *c* being acceptable to student *s* if $c \succ_s \emptyset$ and student *s* acceptable to college *c* if $s \succ_c \emptyset$. Clearly then, preferences are by assumption transitive and complete and hence, rational. The assumption that colleges have preferences over group of students, not only individual students, comes from the fact that we generally think of agents being primarily interested in their *outcomes*, not the parts that form that outcome. The colleges could also be defined to have more general substitutable preferences, see Roth and Sotomayor (1990: pp. 171-177). As student have preferences over colleges, not positions in them, we assume that students find all positions in the same college identical.

It is also noteworthy that as no transfers of any kind are defined to be part of a matching, all aspects of the other side of the market that the agent deems relevant are reflected in the preference ordering, possibly including wages, tuitions, location and so on. The preference relations are ordinal, in other words they contain no cardinal information on preference intensities. The agents are also assumed to care only about their own outcomes: the preferences that students have over colleges are not influenced by whether their friends get admitted, though the stated preferences might be determined in part by expectations concerning how likely it is that they do.

There are also no transfers between agents on the same side of the market, which would allow for agents to influence the preferences that others have over specific matches. So the preferences are exogenous and "final" in these senses. Also, responsive or more generally substitutable preferences ensure that colleges treat students as substitutes, not as complements, so the possibility does not arise that a college with preferences over individuals determined by $\succ_c = s_1, s_2, s_3$ would prefer the group of students $\{s_1, s_2\}$ to any other group, but would find s_1 so worthless without s_2 that it would prefer the group $\{s_2, s_3\}$ to the group $\{s_1, s_3\}$.

When all colleges have a capacity of one, the marriage market problem is obtained as a special case of the college admissions problem. The so-called related marriage market of a college admissions problem has proven to be a useful tool for reaching results for the college admissions model, though many of the conclusions obtained for the marriage

market do not generalize. Roth and Sotomayor (1990) contains a thorough discussion on the basic theory of two-sided matching.

We call the triplet $(S, C, \succ)$, where $\succ = (\succ_s, \succ_c)$, *a* college admissions problem, or simply an economy, when the context is clear. An outcome for the problem is a *matching*, that is, a function μ that maps every student to some college or back to himself or herself, when no match is found, and every college to a group of students no larger than its capacity, with the property that a student *s* is matched to college *c* if and only if college *c* is matched to student *s*. More formally, a matching is $\mu: S \cup C \to 2^S \cup C$ such that for any $s \in S$ and $c \in C$,

1. $|\mu(s)| \leq 1$ for all students $s \in S$ and $\mu(s) \in C$,
2. $|\mu(c)| \leq q_c$ for all colleges $c \in C$ and $\mu(c) \in 2^S$,
3. $\mu(s) = c$ if and only if $s \in \mu(c)$.

We say that an agent *i* prefers a matching μ to another matching μ' if it likes the matches given to it under μ over the ones given to it under μ', that is, $\mu(i) \succ_i \mu'(i)$. A matching μ is *individually rational* if no agent finds one of his matches under μ unacceptable, in other words, for all $s \in S$, $\mu(s) \succ_s \emptyset$ and for all $c \in C$, there is no $s' \in \mu(c)$ such that $\mu(c) \backslash s' \succ_c \mu(c)$, where the last requirement is by responsiveness equivalent to $s' \succ_c \emptyset$ holding for all $s' \in \mu(c)$.

A matching is *stable* if it is individually rational and there is no student *s* and college *c* such that *s* would prefer *c* to the college that the matching gave him, and *c* would prefer *s* to one of the students that the matching gave it, or *s* being acceptable to *c* and *c* having free capacity, as then *s* and *c* would constitute a blocking pair. Formally, there is no such $s \in S$ and $c \in C$ such that

$c \succ_s \mu(s)$, and

$s \succ_c s'$ for some $s' \in \mu(c)$ if $|\mu(c)| = q_c$, or $s \succ_c \emptyset$ if $|\mu(c)| < q_c$.

So a stable matching is blocked neither by some individual nor a blocking pair. Note now how important the assumption that agents only care about their own outcomes is. If

students would care about how the matching played out for their friends, the preference ordering after the market has reached a matching could differ from the preferences that the students had before the market opened, and matchings that would have been stable with respect to the original preferences could be unstable with respect to the new preferences.

A number of important results that concern the set of stable matchings have been established for the college admissions problem. Gale and Shapley (1962) and Roth (1985) show that the set of stable matchings is nonempty for every college admissions problem with responsive college preferences and standard student preferences, and Roth and Sotomayor (1990: pp. 175 – 177) prove that a stable matching exists even if colleges have more general substitutable preferences. However, if there are no restrictions set on preferences of colleges, students' preferences over colleges need to be aligned with each other in a certain strong sense (Dur & Ikizler, 2016). Roth (1984) also shows that if preferences of some students depend on outcomes of other students, the existence of a stable matching is not guaranteed.

It needs to be noted that the assumption of responsiveness is not enough for preferences over individuals to determine unique preferences over groups of individuals. For the same strict preferences that colleges have over individual students, there are differing preferences over groups of students that are all responsive to those preferences over individuals. However, Roth and Sotomayor (1989) prove that for strict preferences over individuals, if a college prefers a stable matching μ to some other stable matching μ', then the college prefers every single student it gets under μ but not under μ' to every student it gets under μ' but not μ. The preferences that colleges have over groups of students matched to it under different stable matchings are in this sense unambiguous.

Roth (1984) shows that when preferences over individuals are strict, the set of students who get a position and positions filled is the same at every stable matching. So a college that does not fill all its positions at some stable matching gets the same number of students at any other stable matching, and a student that does not get to college at some stable matching does not get chosen at any stable matching. Moreover, as a related result we have the so-called rural hospital theorem:

> *Theorem 1* (Roth, 1986). When preferences over individuals are strict, any college that does not fill all its positions at some stable matching is assigned precisely the same set of students at any other stable matching.

What this means is that a college that is not generally highly appreciated among the students cannot hope that there would be some other stable matching where it would get a set of students that it likes better than the set it gets assigned at some given stable matching. If one would like to help such colleges, pushing the market to a different stable matching will not suffice: it has to be in the form of changing the preferences that students have for that college.

There exists also a number of remarkable results on the welfare properties of matchings for the college admissions problem. A matching is called *student-optimal* if there is no matching that every student would find at least as good, and analogously for colleges. A student-optimal stable matching is then student-optimal in the set of stable matchings, and analogously for the college-optimal stable matching. *Pareto efficiency,* or Pareto optimality, or just efficiency, means that nobody could be made better off without somebody being worse off. Then Pareto efficiency for one side of the market means that nobody on that side of the market could be made better off without somebody on that side of the market being worse off. *Weakly Pareto optimal* matching for students is one for which it holds that not all students would be strictly better off at some other matching, though some subset of students potentially would, and analogously for colleges.

Roth (1985) shows that for strict preferences, there exists a college-optimal stable matching that every college finds at least as good as any other stable matching, and a student-optimal stable matching that every student finds at least as good as any other stable matching. This is remarkable in that the interests of one side of the market are aligned in the sense that at the optimal stable matching, no agent on that side of the market would want to change to any other stable matching. Roth and Sotomayor (1990: 163) also show that the stable matching that is optimal for one side of the market is the worst stable matching for the other side of the market. However, Roth establishes also the following result:

> *Theorem 2* (Roth, 1985). When the preferences over individuals are strict, the student-optimal stable matching is weakly Pareto optimal for the students, but the college-optimal stable matching does not need to be even weakly Pareto optimal for the colleges.

So for students, stability implies weak efficiency in the set of all possible matchings, but for colleges, the stable matching that is found at least as good as any other stable matching by all the colleges is not in general the best possible matching for colleges, in the sense of maximizing preferences: there could be some unstable matching that all colleges prefer to the college-optimal stable matching.

These are only properties of a matching, which is just a way of pairing agents given some preference orderings taken as given. Nothing is said on how those matchings would come about, what the agents are allowed to do and what the agents know. If we think of the model, as is standard, as a game where both sides of a match must agree to it, we may expect unstable outcomes not to occur, or at least to swiftly unravel, as blocking pairs will form new pairs, blocking colleges will dismiss unacceptable students and blocking students will reject the position offered.

It is also standard to assume that the preferences of the agents are private information that is known only to them. It is then natural to ask if the preferences that are observed in the market, however they may be inferred from the behavior of the agents, are the same as their true preferences. Do they act in a straightforward manner, always going after the one on the other side of the market that they prefer to the rest available, honestly stating their preference lists if asked? Suppose we have a well-ordered procedure for making matches, which only requires the participants to submit their preference orderings to some third party, which does all the work required for a matching to come about. Call such a procedure a *mechanism*.

A mechanism is a function φ that gives a matching for every college admissions problem. We call a mechanism *stable*, if it always produces a stable matching and *efficient*, if it always produces a Pareto efficient matching. We also say that a mechanism is *strategy-proof* if it makes it a dominant strategy for every agent to state their true preferences, that is, if truth-telling is the best response of every agent to any strategy combinations that the

other agents might choose, in any college admissions problem. It is important to note that a stable mechanism implements a matching that is stable *with respect to the stated preferences*, not the actual (unknown) preferences, and analogously for efficiency.

Denote by P_i an arbitrary reported preference ordering of agent i and by P_{-i} arbitrary preference orderings of the rest of the agents in $S \cup C$. Then let $\varphi(P_i, P_{-i})(i)$ denote the match assigned to agent *i* under the matching that the mechanism yields when the reported preferences are $P = (P_i, P_{-i})$. Then for a strategy-proof mechanism φ, it holds for all agents *i* that

$$\varphi(\succ_i, P_{-i})(i) \succ_i \varphi(P_i, P_{-i})(i),$$

for arbitrary report P_i of agent *i* and arbitrary reports P_{-i} of the other agents. In a college admissions problem with a mechanism specified, agents on both sides of the market submit preference lists and are therefore strategic agents, as the design of the mechanism determines the optimal strategy for an agent, given the beliefs that the agent has about the strategies of the others. It may also be assumed that capacities are only known privately by the colleges, and so colleges may also be asked to state their capacities.

Roth (1982) shows that there is no stable matching mechanism that would be strategy-proof. This is not difficult to prove: it suffices to write an example market for which every stable matching is such that some participant would have been better off by misreporting her preferences. Clearly then, any mechanism that yields one of those stable matchings is vulnerable to manipulation. Also, the following result shows that the two sides of the college admissions market differ fundamentally in this respect.

> *Theorem 3* (Dubins & Freedman, 1981; Roth, 1982). A stable matching mechanism that yields the student-optimal stable matching makes truth-telling a dominant strategy for all students. However, there is no stable matching mechanism that would make truth-telling a dominant strategy for every college.

In particular, a matching mechanism that yields the college-optimal stable matching is not strategy-proof for the colleges. However, it is comforting to know that at least the students can be provided with incentives for truth-telling, because colleges (or schools)

are often public institutions in applications, and consequently their personnel may have less incentives or possibilities for taking advantage of the manipulability of the mechanism.

The below limits-to-manipulations theorem of Demange, Gale and Sotomayor (1987) shows that in a marriage market, participants who have only a single partner over all stable matchings cannot profitably manipulate a mechanism that implements a stable matching.

> *Theorem 4*. (Demange, Gale & Sotomayor, 1987). In a marriage market, let $\succ$ be the true (not necessarily strict) preferences and suppose that P are the reported preferences, where some coalition (of possibly only one member) misstate their preferences. Then there is no matching μ, stable for the reported preferences P, which is preferred to *every* stable matching under the true preferences $\succ$ by all members of the coalition.

As a corollary of the theorem, if there is only one stable matching under $\succ$, then no participant can misstate his or her preferences to gain a preferred partner under any stable matching mechanism (all of which necessarily implement the sole stable matching). Of course, the result does not generalize to the college admissions problem, because of colleges' incentives (Roth, 1985), but Roth (2015b, 2018) considers the theorem still helpful in understanding the empirical observation that stable matching mechanisms seem to be quite immune to manipulation in applications with a small set of stable matchings. Because of this, the size of the set of stable matchings is an important practical consideration for analyzing the incentives generated by a stable mechanism.

We have two further results on the incentives of colleges. Regarding the reported capacities of colleges, we have the following result:

> *Theorem 5* (Sömnez, 1997). No stable matching mechanism makes it a dominant strategy for a college to reveal its capacity in every college admissions problem. In particular, a stable matching mechanism that yields the college-optimal stable matching is not immune to manipulation via capacities.

Furthermore, we have another disappointing result concerning the possibility of preventing colleges and students from having incentives to circumvent the centralized matching by making pre-arranged matches.

> *Theorem 6* (Kesten, 2012; Sönmez, 1999). There is no stable matching mechanism that is non-manipulable via pre-arranged matches. In fact, essentially no matching mechanism is non-manipulable via pre-arranged matches.

The word *essentially* refers to the (very weak) requirement for there to be no matching mechanism that would be non-manipulable via pre-arranged matches, which is that there has to be more students than the capacity of any one of the colleges: $n = |S| > q_c$ for at least one $c \in C$ (Kesten, 2012).

Theorems 4 and 5 may seem surprising, because we might expect that stability would precisely prevent such situations. However, Sönmez (1999) was inspired by the empirical findings that pre-arranged matches seem to occur in some centralized matching markets despite of the clearinghouses using stable matching algorithms (e.g. Roth & Xing, 1994). In any case, based on the theory, we would expect that centralized markets utilizing unstable mechanisms would tend to leave much larger incentives for strategic behavior, and consequently would exhibit more pre-arrangement of matches.

Indeed, there is both empirical (Roth, 1991) and experimental (Kagel & Roth, 2000) evidence suggesting that stability of the matching mechanism used is an important factor for preventing the kind of unraveling described by Roth and Xing (1994), in which pre-arrangements play a central role (see Roth (2002) for a discussion on the topic). There is also some anecdotal evidence that in the former, partly decentralized NYC high school choice plan matching mechanism some high schools stated capacities lower than actual, placing the rest of the students outside of the centralized matching process, evidently because the outcomes tended to be unstable (Abdulkadiroğlu et al, 2009; Roth, 2015a: pp. 106 – 110).

3.2 The school choice and student admissions problems

On the other hand, the student placement problem of Balinski and Sönmez (1998) and the standard school choice problem of Abdulkadiroğlu and Sönmez (2003) are cases of one-

sided matching markets, or priority-based allocation problems, in which students look for school seats and school seats are simply (indivisible) objects to be consumed. Students are assigned to school seats on the basis of the preference lists they submit and priority orderings of the schools. As they are asked to state preference lists, students are strategic agents and so the question of whether a given mechanism is strategy-proof for students remains important. However, schools are not strategic agents, as the priority orderings that schools have over students are given by some fixed criteria, and the capacities of the schools are also taken as exogenously determined and publicly known. Consequently, also the situations of theorems 5 and 6 are assumed away.

The student placement problem and the school choice problem differ in that in the student placement problem, the priorities of the colleges are given by a centralized admission examination, where each college belongs to one of several test categories, while in the school choice problem, the priorities are given by some, usually quite coarse, politically determined criteria. This distinction may seem somewhat artificial but has both theoretical and practical relevance, as the coarser criteria of school choice problems often make schools indifferent between various students, a situation that has serious consequences for stability and efficiency (Erdil & Ergin, 2008).

We now denote the priority ordering of school c by π_c to emphasize the difference between priorities and preferences. However, to keep matters simple, below we will generally refer to college preferences even when presenting results originally obtained in a priority-based allocation context. Allocation would also be a more correct term than matching in this context, but we will follow convention and use the terms interchangeably. The notation of the college admissions problem is used otherwise, and the rest of its assumption are kept. However, some new terms need to be defined. A matching μ is *non-wasteful* if whenever some student s prefers some college c to his match under μ, c has its capacity filled under μ: for all students $s \in S$,

$$\text{if } c \succ_s \mu(s), \text{ then } |\mu(c)| = q_c.$$

In such priority-based allocation problems, the existence of a centralized matching mechanism is of course always assumed, as some procedure is required for allocating student seats when schools are not agents capable of looking for matches themselves. For

the same reason, stability, a central issue for college admissions problems, has no meaning in school choice and student placement problems. However, stability is closely related to the concept of *fairness*, which says that if student *s* prefers the allocation *c* of another student *s′*, then *s* has a lower priority than *s′* for the school seat *c* allocated to *s′*: for all students $s, s' \in S$,

> if $\mu(s') \succ_s \mu(s)$, then $s'\pi_c s$.

Balinski and Sömnez (1999) show that an allocation in a school choice or student admissions problem is individually rational, non-wasteful and if and only if the corresponding matching is stable for the corresponding college admissions problem.

In addition to the above discussed incentive concerns, the welfare of an allocation is not evaluated the same way under the models. In the college admissions problem, considering the welfare of agents on both sides of the market is central. In the student placement and school choice problems, only the welfare of the students is considered, as schools are not seen as agents, but only as collections of objects to be consumed. This somewhat simplifies welfare analysis. The question then naturally raises of how good mechanisms should we hope to discover. Theorems 2 and 3 show that we cannot expect to find strategy-proof mechanisms for the college admissions model, and that for colleges, stability does not imply even weak Pareto efficiency. However, in the student admissions and school choice models, we assume away such complications. Unfortunately, we still have the following result:

> *Theorem 7* (Kesten, 2010). No mechanism that is efficient and strategy-proof with respect to students' preferences is stable.

So no mechanism achieves everything. If we insist on the mechanism being strategy-proof, even only for students, and also stable, we cannot expect it to be efficient in general.

3.3 Mechanisms

This section presents the algorithms that feature the most prominently in the matching market theory and surveys how these algorithms relate to each other and the results discussed above. We also briefly refer to related mechanisms that are not as important in

the context of college admissions, but nonetheless merit mention. Discussing the properties of the mechanisms is a good introduction to the practical relevance of the above results, and also to the issues that concern the design of admissions procedures in a more extensive sense.

As is customary for illustrative purposes, we describe the algorithms as if students really went from door to door when applying for different colleges (as would be the case with a decentralized admissions procedure – note that the algorithms could be seen to be simple models of decentralized matching markets), though in real clearinghouses, applicants and colleges only need to report a list of preferences, which a computer then uses to work through the algorithm to produce a matching.

3.3.1 Deferred acceptance mechanism

The most famous mechanism is the widely applied student-proposing deferred acceptance (sDA) algorithm of Gale and Shapley (1962), often also called the Gale-Shapley mechanism, which proceeds as follows:

Round 1. Every student applies to her most preferred college. Every college tentatively accepts from its applicants its most preferred students up to its capacity q_c and rejects the rest, if the number of applicants exceeds its capacity. If the number of students who regard the college as their first preference is less than the capacity of the college, the college tentatively accepts all applicants.

Generally, in

Round k. Every student rejected in round $k-1$ applies to the college she prefers to the rest among those colleges that have not yet rejected her. Every college tentatively accepts from its applicants (pooling both those that applied in this round and those that were tentatively accepted in the previous rounds) its most preferred students up to its capacity q_c and rejects the rest, if the number of applicants exceeds its capacity. If the number of students who regard the college as their first preference is less than the capacity of the college, the college tentatively accepts all applicants.

The algorithm terminates after any round *k* in which no applicants are rejected, or students still left without a place in college have proposed to all colleges they find acceptable. At that point, the tentative acceptances of round *k* turn into final acceptances, and the match is fixed.

It is noteworthy that during the algorithm, no students propose to the same college twice. That would be pointless, because if a student is rejected by a college during stage *k*, she will certainly be rejected at any later stage $k + j, j \in \mathbb{N}$, as the college can only hold a more preferred set of students at a later stage.

The college-proposing deferred acceptance algorithm is analogous to the student-proposing variant, but it has colleges propose to students and students tentatively accept college seats until no college place is rejected, or colleges with spare capacity left have proposed to all students they consider acceptable. The serial dictatorship mechanism (SD) equals the student-proposing deferred acceptance algorithm which equals the college-proposing deferred acceptance algorithm when all colleges have the same preferences over students (Fack, Grenet & He, 2019). In it, the highest ranked student picks a seat at her favorite college, and generally, the *k*th ranked student picks a seat at her favorite college among those with unfilled seats left. Balinski and Sömnez (1999) also show that the multi-category serial dictatorship mechanism used to allocate students to colleges in Turkey always produces the same matching as the college-proposing deferred acceptance algorithm.

The student-proposing deferred acceptance algorithm implements the student-optimal stable allocation alluded to in theorem 2, and likewise the college-proposing deferred acceptance algorithm implements the college-optimal stable matching (Gale and Shapley, 1962; Roth, 1985). Therefore, the deferred acceptance mechanism is stable (i.e. fair with respect to the students' preferences), and by theorem 3, we know that the student-proposing variant is strategy-proof for students, though not for colleges (as is none other stable mechanism). However, as implied by theorem 2, the student-proposing deferred acceptance algorithm is not efficient with respect to preferences of students in the set of all matchings (only weakly so), and the college-proposing version is not even weakly efficient for colleges in the set of all matchings. Ergin (2002) characterizes an acyclity restriction that is needed on preferences (priorities) of colleges to guarantee that the

student-proposing deferred acceptance algorithm produces a Pareto efficient outcome for students.

The student-proposing deferred acceptance algorithm is also not immune to manipulation via capacities (Kesten, 2012) but it is in certain sense less manipulable via capacities than any other *stable* mechanism (Ehlers, 2010). Though both are manipulable via pre-arranged matches, the student-proposing variant less so than the college-proposing one (Afacan, 2013). Kojima (2007) presents the minimal restrictions on college preferences to ensure the non-manipulability via pre-arranged matches and capacities and notes that they are unlikely to hold in applications. Roth (2008b) discusses the properties and applications of deferred acceptance algorithms in length and Kojima and Manea (2010) provide an axiomatization of the student-proposing deferred acceptance mechanism, i.e. the conditions on a matching mechanism which make it the sDA.

3.3.2 Top trading cycles mechanism

The top trading cycles mechanism (TTC) of Shapley and Scarf (1974) is another theoretically prominent mechanism, though not in very wide use in college and school choice situations and is usually presented in as a mechanism for priority-based allocation problems rather than two-sided matching markets. It can be seen to let students to trade their priorities at different colleges to gain mutually better matches for the students. It proceeds as follows:

Round 1. Every student points to her most preferred college and every college points to its most preferred student. A cycle is an ordered list of students and colleges $(s_1, c_1, s_2, c_2, \dots, s_k, c_k)$, where s_1 points to c_1, c_1 points to s_2, s_2 points to c_2 and so on, until finally c_k points to s_1 and a cycle forms. Because of finiteness of the sets of students and colleges, at least one cycle will always form, and no student can partake in more than one cycle and no college can be in more than one cycle in one round (Abdulkadiroğlu & Sönmez, 2003). Students in a cycle get a seat in the college which they point at and are removed.

Generally, in

Round k. Every student still without a seat point at her favorite college among those with unfilled seats left, and every college with unfilled seats points to its most preferred student among the remaining students. At least one cycle will form, students in a cycle get a seat in the college that they point at and are removed.

The algorithm terminates when all students are assigned a seat, or all colleges are at full capacity or the remaining students do not find any of the colleges with capacity left acceptable, or none of the colleges with capacity left find any of the remaining students acceptable. The top trading cycles mechanism is efficient with respect to the students' preferences and strategy-proof for students, but unstable (Abdulkadiroğlu & Sönmez, 2003), showcasing theorems 2 and 7: a mechanism that produces a matching that students (weakly) prefer to the student optimal stable matching cannot be stable. There is a fundamental conflict between stability and Pareto efficiency. In the vocabulary of the school choice problem, the top trading cycles mechanism is unfair.

Kesten (2006) strengthens the notion of acyclicality introduced by Ergin (2002) to provide a restriction on college preferences under which the student-proposing deferred acceptance and the top trading cycles algorithms are equivalent, meaning that sDA is efficient and TTC is stable. However, as is the case for the acyclicality condition of Ergin and the conditions Kojima (2007) finds for sDA, the social planner might not want to restrict the preference formation of colleges in such a way for other reasons, nor are the conditions likely to hold in applications if not enforced.

Strikingly, the top trading cycles mechanism is also immune to manipulation via capacities (Kesten, 2012), highlighting the counter-intuitive conflict between stability and non-manipulability via capacities stated in theorem 5.

3.3.3 Boston mechanism

The so-called Boston mechanism, presented in Abdulkadiroğlu and Sönmez (2003) and Abdulkadiroğlu et al. (2005) and of which many variants have been used in various school districts in the United States, is closely related to the student-proposing deferred acceptance algorithm, but in it the acceptances are final in every round (therefore sometimes called an immediate acceptance algorithm). It proceeds in the following way:

Round 1. Every student applies to her most preferred college. Every college accepts from its applicants its most preferred students up to its capacity q_c and rejects the rest, if the number of applicants exceeds its capacity. If the number of students who regard the college as their first preference is less than the capacity of the college, the college accepts all applicants.

Round 2. Every student rejected in the first round apply to her second most preferred college. Every college *with capacity left* accepts from its applicants its most preferred students up to its capacity q_c and rejects the rest, if the number of applicants exceeds its remaining capacity. If the number of students who regard the college as their second preference is less than the remaining capacity of the college, the college accepts all applicants.

Generally, in

Round k. Every student rejected in round $k-1$ applies to her *k*th most preferred college. Every college *with capacity left* accepts from its applicants its most preferred students up to its capacity q_c and rejects the rest, if the number of applicants exceeds its remaining capacity. If the number of students who regard the college as their second preference is less than the remaining capacity of the college, the college accepts all applicants.

The algorithm concludes after any round *k* in which there are no rejections, or the students still left without a place in college have no colleges they consider acceptable left to apply to. After the first round, all students who get admitted to their first preference are ensured a seat in it, and popular schools are therefore likely to be full (with final matches) already after the first round. The Boston mechanism can therefore be seen as prioritizing first preferences, and like TTC, it is efficient with respect to the students' preferences (Abdulkadiroğlu & Sönmez, 2003). Concerning strategic behavior by colleges, it makes reporting their true preferences a dominant strategy for colleges (Ergin & Sömnez, 2006) and is immune to manipulation via capacities (Kesten, 2012).

However, the Boston mechanism suffers from a major drawback: it is neither strategy-proof for students nor stable with respect to the stated preferences (Abdulkadiroğlu & Sönmez, 2003), though the meaningfulness of the concept of stability (*with respect to the*

stated preferences) decreases as the extent of report manipulation increases. Similarly, the efficiency is with respect to the *reported* preferences, not the unknown actual preferences, and with serious misreporting of preferences present, the outcome is unlikely to be efficient with the respect to the true preferences.

The manipulability of the Boston mechanism is easy to see from the description of the procedure. As the more popular colleges are likely to fill their seats during the first one or two rounds, a student who does not get into his first choice may have to settle for a much less preferred college. Because of this, the Boston mechanism induces a preference revelation game where a student must trade his preferences against the probability of getting admitted to various colleges, when compiling a list of reported preferences to maximize his expected utility.

Simply stating the true preferences are unlikely to maximize expected utility, as Pathak and Sömnez (2008) show: a game induced by Boston mechanism with both sincere and sophisticated (who select their reports as best responses to the reports of the others) students present has as its Nash equilibrium outcomes the set of stable matchings of an otherwise similar economy, but where the sincere students relinquish their priorities to the sophisticated students. Moreover, every sophisticated player weakly prefers his assignment under the game induced by the Boston mechanism to the outcome of the student-proposing deferred acceptance mechanism (which is the student-optimal stable matching). In the case where all students are sophisticated, the set of Nash equilibrium matchings of the Boston game equals the set of stable matchings of the economy (Ergin & Sömnez, 2006; Kojima, 2008), and then the student-proposing deferred acceptance mechanism is clearly superior to the Boston mechanism from the viewpoint of the students.

Of course, these are game theoretic results that rely on the ability of the sophisticated players to coordinate their actions so as to bring about their preferred equilibrium outcome, which comes about naturally in the perfect information setting of a theoretical game but are not so likely in the less than perfect informational environment of real admissions procedures. The concern of spurious efficiency highlights the possibly paramount importance of strategy-proofness, but the fact that a mechanism is not strategy-proof does not have to mean that the expected gains from misreporting would be large,

nor that there would be empirically significant misreporting in applications. Indeed, Roth and Rothblum (1999) show that in a low information environment, students' payoffs from misreporting are low for the college-proposing deferred acceptance mechanism, even though it is not strategy-proof for them.

However, Chen and Sömnez (2006) provide evidence that compared to the top trading cycles and student-proposing deferred acceptance mechanisms, the Boston mechanism is more likely to be manipulated in an experimental setting, and consequently less efficient with respect to the true preferences. Abdulkadiroğlu et al. (2006) also describe some empirical patterns suggesting differing level of sophistication among the applicants to Boston Public Schools, and the fact that there were parents' groups dedicated to discussing optimal reporting strategies is in itself indicative of strategic behavior (Pathak and Sömnez (2008) note that at least one parents' group opposed abandoning the Boston mechanism).

3.3.4 Strategic behavior in strategy-proof environments and fragility of strategy-proofness

Above we discussed the issues that arise with mechanisms that are not strategy-proof and consequently force students to act strategically. Because we do not directly observe the true preferences, it is not straightforward to assess the extent to which a mechanism is manipulated. Consequently, it is tempting to conclude that participants have a good understanding of the mechanisms and act to maximize their expected payoffs in terms of the matches. However, numerous experimental studies document that a significant proportion of applicants misreport their preferences even under strategy-proof mechanisms (e.g. Chen & Sönmez, 2006; Featherstone & Niederle, 2016; Klijn, Pais & Vorsatz, 2013).

More worryingly, recent empirical evidence points to the same direction (Hassidim, Marciano, Romm & Shorrer, 2017). Hassidim, Romm and Shorrer (2016) study a college admissions procedure where applicants are asked to indicate their preferences over alternatives that admit a natural ranking, i.e. the same study track with and without a funding and find that a significant fraction of applicants try to manipulate the student-reporting deferred acceptance algorithm. Shorrer and Sóvágó (2017) report similar results in a similar matching-with-contracts setting in Hungarian college admissions. Rees-Jones

(2018) combines reported preferences with survey responses and finds misreporting in the American residency program for new physicians.

These studies indicate that such mistaken misreporting is more common for those with lower cognitive abilities and those applying to more competitive programs. Not surprisingly, mistakes seem more common when the stakes are lower. Such findings indicate a significant failure to act rationally (at least with respect to any standard preferences) and raise concerns about resulting effects on equity in admissions.

Hassidim et al. (2017) identify several reasons for mistaken misreporting. If it is not specified clearly in the instructions, the applicants may fail to understand that the mechanism is strategy-proof. Moreover, even if the instructions advice the applicants to submit their true preferences (preferably with an explanation of the algorithm), the applicants may not trust the advice and also fail to identify truth-telling as the dominant strategy themselves. The applicants may even believe that although the mechanism presented is strategy-proof, the policy maker will not actually utilize it in matchmaking. Another reason is that the applicants may not bother to list the choices they are sure they will not get admitted into, which is very evident in admissions procedures that employ entrance examinations: a student will have a probability of zero to get to study any subject she does not take an examination in, so there is nothing to gain from listing such choices (but possibly a psychological cost to pay, if the participant cares not only about her assignment – see Köszegi (2006) for a behavioral model).

Finally, Hassidim et al. (2017) note that applicants may have social preferences, which may explain why some students rank funded positions lower than unfunded positions, if they see others as more deserving of the financial help. However, such preferences do not seem likely to affect the choice of college, or other similar personally very significant assignment. As another type of social preferences, Aygün and Turhan (2017) describe a case where there is a stigma attached to funded positions, explaining why many applicants prefer regular unfunded positions to the funded ones.

Again, empirical results have spurred new theoretical research. Ashlagi and Gonczarowski (2018) utilize a property of mechanisms called *obvious strategy-proofness*, defined by Li (2017a) in a more general mechanism design setting, and show that no

stable mechanism is obviously strategy-proof for students. Ashlagi and Gonczarowski conclude that there may not be any alternative way to describe the deferred acceptance mechanism in such a way that makes its strategy-proofness more obvious to participants. They note that the social planner must then try to ensure truthful participation by gaining the trust of the applicants so that they both trust its advice and do not suspect the designer of deviating from the announced mechanism.

The literature also shows that strategy-proofness is also fragile in a theoretical sense. Haeringer and Klijn (2009) show that otherwise strategy-proof mechanisms are manipulable if applicants can report their preferences over only a fixed number $k < |C|$ of colleges, i.e. the length of the list of reported preferences is constrained, as is very common in applications. Calsamiglia, Haeringer and Klijn (2010) study such constraints in an experimental setting and find largely the results that Haeringer and Klijn theoretically predict: truth-telling is reduced, and consequently also stability and efficiency (with respect to true applicant preferences).

Fack, Grenet and He (2019) study more general *application costs* where applicants face a constant marginal cost per college reported after the first *K* choices (nesting the model of Haeringer and Klijn) and similarly show that the student-proposing deferred acceptance algorithm ceases to be strategy-proof. Pathak and Sömnez (2013) provide an approach for comparing the manipulability of mechanisms and show that the manipulability of the student-proposing deferred acceptance algorithm decreases with the constraint *k* on the report length and that it is less manipulable than the Boston mechanism with the same constraint *k*.

3.3.5 Large market results

Kojima and Pathak (2009) prove that as the market grows large (under certain loose regularity conditions and the requirement that students only rank a small proportion of colleges), the proportion of colleges that can benefit from misstating their preferences in the student-proposing deferred acceptance mechanism tends to zero. Moreover, also colleges' incentives to manipulate the sDA via capacities and pre-arranged matches vanishes in a large market. The intuition is that the proportion of colleges that are matched to the same set of students in all stable matchings tends to one as the market grows. By

contrast they show that the incentives of students to manipulate the Boston mechanism remain large as the market size grows, demonstrating that the advantage that the sDA has over the Boston mechanism with regards to students' incentives is robust to large market sizes, while the advantages that the Boston mechanism has regarding the incentives of colleges vanishes in large markets.

Moreover, Lee (2018) shows under weaker assumptions that the proportion of colleges with significant incentives to manipulate the student-proposing deferred acceptance mechanism vanish in large markets. Azevedo and Budish (2019) also study strategy-proofness in large markets and introduce the property of *strategy-proofness in the large*, which they show to hold for strategy-proof mechanisms but not for the Boston mechanism. They also try to assess the size of the market required for strategy-proofness in the large to hold.

Azevedo and Leshno (2016) develop a supply and demand framework for two-sided matching markets, which can be used to analyze the asymptotics of matching mechanisms. In their model, only the number of students grows large, i.e. a continuum of students is matched to a constant number of colleges, which may be more realistic than assuming that the number of colleges grows without bound. Stable matchings are characterized by college cutoffs, which determine the set of students matched to a given college. Azevedo and Leshno find that the set of stable matchings converges to the unique stable matching of the continuum model when the number of students grows. Che, Kim and Kojima (2019) use a similar setting to show that a stable matching does exist with a continuum of students even when colleges' preferences over students exhibit complementarities.

Ashlagi, Kanoria and Leshno (2017) show that even with a slight difference in the number of college seats and the number of students, the number of stable matchings will be very small. This holds regardless of market size, provided that colleges have responsive preferences and are small relative to the market. This may explain why the set of stable matchings with respect to reported preferences is often small in applications (Roth, 2015b), and together with theorem 4 of Demange, Gale and Sotomayor (1987), indicates little room for beneficial strategic behavior in such environments.

While there is little work towards showing how large the market must be for the asymptotic results to be a good approximation, these results may help to explain the empirical observation that the sDA tends to work quite well in large markets (Roth, 2002, 2018), at least in the sense of not being prone to unraveling. This even though its incentive properties are not theoretically faultless, as shown by Roth (1982) and Dubins and Freedman (1981).

3.4 Empirical analysis of matching markets

Recently, a lot of work of has gone into econometric analysis of matching situations (Chiappori & Salanié, 2016). In the school and college choice settings, such empirical work has mostly focused on estimating preferences for analyzing the welfare gains from different mechanisms, often under the assumption of truth-telling under the student-proposing deferred acceptance mechanism, as in Abdulkadiroğlu, Agarwal and Pathak (2017) and Abdulkadiroğlu et al. (2009). Agarwal and Somaini (2018) and Fack et al. (2019) take the possibility of strategic behavior in strategy-proof mechanisms seriously and assess alternative assumptions for identifying preferences, including a weaker version of truth-telling, stability of the matching and that participants use only undominated strategies.

However, Fack et al. (2019) find that though the assumption of stability seems to work the best in their context of high school choice in one Parisian district, the estimated models do not perform particularly well in predicting the observed assignments. This is likely to reflect both insufficient covariates and weak information contained in reported preferences, highlighting once again that policy analysis based on untruthful or incomplete preference information is liable to be misguided.

4 DESIGNING A COLLEGE ADMISSIONS PROCEDURE

This section discusses the aims of a college admissions procedure, what a market design approach to college admissions entails and the empirical and normative questions which the policy maker must confront when designing such a procedure. We also briefly discuss the theoretical work that aims to understand the functioning of decentralized college admissions markets relative to the properties of centralized clearinghouses discussed in the previous chapter.

4.1 The aims of a college admissions procedure

As is evident with the recent reforms in Finland, policy makers may have multiple aspirations for a mechanism such as a college admissions procedure. The reform was initially announced with the aim of speeding up the transition of new high school graduated to higher education (VNK, 2015), and as discussed above in the context of entrance examinations, universities also report to regard many aspects of the admissions procedure important: sorting the applicants based on their motivation, abilities, and suitability, and informing the applicants about the subject they are applying to study. It is also hoped that more motivated students graduate faster, and if the admissions procedure succeeds in choosing the most motivated applicants, it also helps in achieving faster transitions from higher education to working life (Ahola et al, 2018), another goal sought by policy makers (e.g. VNK, 2015). Students who get to specialize on the subjects they are interested would also seem to be more likely to make better workers, which will then result in better economic performance for the whole economy and higher tax income for the state.

Besides of these concerns for financing of the public sector that tend to drive the ambitions for reform, satisfying the preferences of the applicants to the highest extent possible would also seem to be a worthy goal for itself, for many normative benchmarks from utilitarianism to the objective list or capabilities approaches of Rawls (1971, 2001), Sen (2009) and Nussbaum (2011) and also to perfectionistic ideals. Of course, the better economic performance that might follow from more motivated students also brings more general utilitarian gains in addition to the gains accruing to the applicants through

preference satisfaction, and likewise contribute to the primary goods allocation of the worst off in the Rawlsian case.

Whether the preferences of colleges should be given any concern is another topic. As discussed above in the context of entrance examinations, some see the autonomy of colleges as a fundamental design objective, which naturally would leads one to consider satisfying their preferences as important (in the extreme, even as a reason to abolish all legal requirements to partake in the centralized matching mechanism). However, it is also possible to view the preferences of colleges as instrumentally important: insofar as the preferences of colleges concern ability and suitability for the profession, satisfying them as far as possible is again instrumental for achieving better overall economic outcomes.

Although these goals may seem diverse, they broadly concern the compatibility between students and colleges: if preferences of students are as well matched with the preferences of the colleges (suitability for studies, abilities) as possible, good outcomes will follow. Pekkarinen and Sarvimäki (2016) list four criterions on what defines a good college admissions system:

1. The preferences of applicants and colleges are satisfied as well as possible given the preferences of all,
2. Factors deemed irrelevant, such as family background, gender and place of residency do not yield advantages or disadvantages to applicants,
3. Applicants are not unreasonably penalized for past mistakes,
4. The procedure of student assignment does not waste resources, for example, in the form of requiring substantial time and financial investments from applicants and schools.

Of these, numbers 1 and 2 concern the compatibility of students and colleges, where the second criterion assures that factors that have no bearing on innate capabilities of applicants do not influence allocations. At the same time, the second criterion also articulates the usual requirement of equality of opportunity. The second criterion can also be seen as disallowing situations of justified envy (i.e. instability), where somebody with higher scores loses a seat she would like more to somebody with lower scores. In any case, requiring no justified envy is a requirement the public is likely to see important.

The third criterion presents a normative constraint on the mechanism: applicants who did not do well in studies in their early life should still have a possibility to get admitted to higher education later in life, though not necessarily as good chance as the average new high school graduate. The fourth criterion states a somewhat loose efficiency requirement. It is noteworthy that it conflicts with the first criterion if more expensive admissions procedures help to increase the compatibility between students and colleges, and must then be understood to require that more expensive procedures are only acceptable up to the point where costs equal, in some sense, the value of improved aggregate matchings. The fourth criterion could also be seen to require strategy-proofness because of mental and financial costs related to determining optimal strategy. Pathak (2017) notes how strategy-proofness is in the context of real school choice mechanisms the design objective that the public seems to find the most important, while the theoretical literature has seen it purely as an incentive constraint for achieving the consequentialist objective of satisfying the preferences of students over schools.

Keeping the proportions of men and women in higher education relatively stable and equal is often emphasized as one design objective, especially in context of policy changes. In 2017, approximately 53% of students in higher education were women (Official Statistics of Finland, 2018b). Abandoning the entrance examinations has been feared by some to lead to a significant reduction in the number of men admitted, as men are often believed to do worse in high school (Ahola et al, 2018). However, Karhu (2018) disputes the claim that men do worse: while women complete more subjects in the matriculation examinations and do a bit better in most, they tend to do worse in advanced mathematics, which gets a significant weighting in admittance to many competitive college programs currently (e.g. in the case of business schools, Hyvönen, 2019). In general, the differences are not large.

Ahola et al. (2018) note that men did a bit better in the system based on entrance examinations in 2016: the proportion of admitted to applicants was higher for men than women (in terms of admittance to the stated first preference), but the differences vary from sector to sector. Taking the most demanded sectors as an example, also because stating a first preference for one of them is more likely to be truthful, women did worse in medicine but were more likely to get admitted to study law, while in business studies there was very little difference.

Hyvönen (2019) finds that the proportion of women in those admitted relative to the proportion of women in applicants has increased marginally (by around 5%) in business schools since 2015, concurrently with the changes that have increased the role of matriculation examination grades and high school curriculum in admittance. More strikingly, when medical schools unified their admissions procedures in 2018 so that the same entrance examination is valid for all of them (i.e. effectively allowing application to multiple medical schools at the same time) the proportion of women in the set of admitted students increased from around 55% to 65%, more closely now reflecting the proportion of women in applicants, which was 64% (Seppänen, 2019). Whether these findings correspond to causal relations is dubious, though the change in medical school students' gender distribution is large enough to make it quite believable.

In any case, it is not clear how such concerns fit into the criterions of Pekkarinen and Sarvimäki (2016) above. Requiring equality of opportunity as in the second criterion does not prohibit women from being a larger proportion of college students, if they on average score higher than men on the admittance criteria deemed optimal for ranking applicants on the basis of the capabilities required for the subject. On the contrary, it would seem that selecting admittance criteria to ensure that men and women do equally well on average would discriminate against women, if such criteria were not deemed optimal for sorting the applicants based on required capabilities. On the other hand, if it was not possible to very exactly define the capabilities required for the studies (say, in terms of performance in the matriculation examinations), then it would be difficult to speak of discrimination to one direction or another.

Of course, it is also possible to include an additional criterion that conflicts with the requirement of equality of opportunity. Establishing quotas for men and women in programs where the gender distribution is thought to be too biased (and similarly for other groups deemed to be underrepresented) was recommended in one earlier memorandum of the Ministry of Education and Culture (OKM, 2012a), though the writers were unable to admit that this would deteriorate the equality of opportunity and the proposition was ultimately not implemented. The rationale in OKM (2012a) was that the biased gender distribution in many professions (teachers in comprehensive schools, for example) imposes severe costs on the society, in part because of role models presented to children and adolescents. It is difficult to assess if such claims have merit. As OKM (2016) remind,

the gender distribution in higher education reflects decisions made earlier in life: in 2017, women constituted 58% of both high school students and new graduates (Official Statistics of Finland, 2018a).

4.2 Preferences and welfare

The demand for education stems from the preferences of the applicants. Preferences concerning such an important good as education are a complicated matter. It is not only about what the person prefers to study for the next few years, as education determines much of what the person is going to do over her life and has a large effect on her expected lifetime income. Financially, higher education is a good investment in Finland: Koerselman and Uusitalo (2014) report that taking into account taxes and transfers, someone with a college degree can expect to have disposable income of around 60-70% higher than those with only vocational education, though the expected income differs widely between subjects. Of course, there are other potential reasons to attend college, such as interest in the subject of choice, an experience of higher social standing and so on.

4.2.1 Preference formation, truthful reporting and welfare analysis

The way how economists usually abstract away details of emotions and desires when considering choices, preferences and welfare is criticized by Nussbaum (2016), among others. Matching models include simple ordinal preference relations of the above form as a representation of the mental entities that explain choices and reveal the individual's evaluations of her welfare. These preference relations are taken as exogenously determined, and what they entail is not usually discussed very seriously. As discussed above, the preference relations are also usually taken to include all relevant aspects of the situation, in this case including for students all things that could affect preference for a college over another. This rules out discussions of preference formation: how colleges formulate their preferences over students and what the preferences of students comprise.

The college admissions problem is also static. In real college admission procedures, the applicants arrive sequentially in lumps, but as the time between consecutive admissions procedures is relatively long and the flow of applicants is not continuous, it seems a

reasonable simplification to design clearing houses based on static models[5]. However, as there are no more periods than one, questions concerning optimal application and admission strategies over time and evolving preferences do not appear.

Quite simply, in these models student *s* preferring college C_1 to college C_2 means that given a free choice between them, she chooses C_1, and *s* never chooses C_2 when C_1 is available (Roth & Sotomayor, 1990: pp. 17-18). We would believe that real preference relations depend on a variety of factors, in that a preference for C_1 over C_2 means that C_1 scores sufficiently much higher than C_2 in the set of the characteristics deemed important by the applicant (given her information on the characteristics): her intrinsic interest in the subject, demand for labor with the given degree and the geographical dispersion of the demand, the expected income for a person with the degree, the difficulty level of the studies, the difficulty of getting admitted, distance from her hometown, whether or not her friends attend college in the same location, and so on.

In other words, the preferences are not purely over the alternative studies, and moreover, the choices that we observe may also include the effect of binding budget constraints and incomplete financial markets (financial constraints are not that large of an issue in Finland, because there are no tuition fees and studying is heavily subsidized, though as noted above, preparing for entrance examinations can be quite costly). Here we could then make the distinction between preferences over study subjects versus preferences over the alternative study paths as a whole, which are ultimately what determines choices and therefore all that we usually observe.

Of course, it is possible to model preference relations instead of taking them as exogenously determined, allowing for dependence on factors like the abovementioned. However, endogenizing more factors to a model comes at the cost of complexity. Moreover, the objective in matching theory is not to analyze preference formation but to examine the matching market outcomes that given preferences yield.

While simplifying assumptions are necessary for building a theory, these become important issues in practice, mainly because we would like to make welfare evaluations

[5] There are some interesting recent work looking into designing mechanisms for dynamic markets, e.g. Baccara, Lee and Yariv (2018) and Doval (2019).

(or general normative evaluations) based on satisfaction of the stated preferences, as embodied in criterion 1 of Pekkarinen and Sarvimäki (2016), but also because we would like to use the theory as a guide for analyzing the stability and other aspects of real mechanisms. If mechanism φ is equal to another mechanism ψ in all other relevant aspects but always satisfies the stated preferences better, we would like to say that φ is better than ψ, or dominates it. But this requires assuming that the stated preferences are somehow a good measure of welfare. As noted above, the (constrained) preferences over study paths may be due to various factors. The question then arises of what the society sees as normatively relevant reasons behind choices. Exogenous preferences can also lead to situations where we may be falsely lead to believe a mechanism to be strategy-proof, when it actually is not, as might be in the case of colleges employing costly entrance examinations to determine preferences over students.

It then becomes important to assess whether the application under consideration violates the modelling assumptions to an extent where the model is unlikely to contribute much to our understanding of the situation or yield reliable predictions. In real-life (centralized) college admissions procedures the applicants are asked to provide their preference relation, and for welfare evaluations and other applications of the model it must then be asked if

1. Real-life preferences have the same structure as that defined for agents' preferences in the model,
2. The reported preferences equal the true preferences,
3. The preferences over the alternatives in question are sufficient for making welfare assessments on different mechanisms.

First of all, it is assumed that the students' preference relations are rational, which just requires that the applicants can rank all their options in an internally consistent way. This is not a particularly strong assumption in the context of college choice, because the decisions concerning education are significant enough to require serious thought, which seems likely prevent violations of transitivity. Similarly, ruling out transfers between agents on the same side of the market is clearly appropriate.

The assumption that individuals only care about their own outcomes is clearly false to some extent, as students certainly care about if their friends get admitted to nearby colleges. This is generalization of the problem of allocating doctors to internships in the presence of couples: a mechanism that is strategy-proof for standard preferences can still allow for strategic behavior when student preferences exhibit such interdependencies (few mechanisms used either in theory or practice even allow reporting such preferences) and no mechanism is stable for such preferences (Roth, 1984). However, it would seem unlikely that this would reverse a large proportion of preference orderings on average, though it is ultimately an empirical question. Another question is whether the policy maker should consider such preferences "valid": if student *s* prefers a business school to engineering studies if and only if his friend also gets admitted to the business school, should we think of it as a welfare loss when *s* gets stuck in the business school without his friend?

This leads us to the more general issue of evolving preferences, where preferences before and after the matching has taken place differ. Of course, in reality matchings that appear at first stable can over time become unstable, as some students find out that they did not like the subject after all (information increases), circumstances in the labor market change and so on. There is also the curious possibility of truly unstable preferences, where preference relations reverse from time to time, grass always being greener on the other side of the fence (these are what Elster (1982) calls counteradaptive preferences). However, evolving and unstable preferences present a problem for welfare analysis, because if matchings that seem preference maximizing and stable ex ante become inefficient to a considerable extent after some time, it would seem dubious to make welfare assessments on the basis of ex ante preference satisfaction.

Exogenous preferences also hide away what Sen (1977) calls commitment, which could lead to moral concerns influencing an agent to make application choices that do not correspond to what he believes would maximize his individual welfare. Then observed choices, which in the case of centralized college admissions are the reported preferences, need not be equal to the true preferences (or maybe we could say that the true preferences are altruistic, i.e. not corresponding to personal welfare maximization – in any case, the observed choices do not maximize personal welfare). Commitment would present issues,

if applicants regularly opted for choices they do not believe to maximize their own welfare because of concerns for other people, which might not be very likely.

Relatedly, Elster (1982) highlights the case of adaptive preferences, where a person adapts to his circumstances, and his preferences then reflect his set of feasible choices and social expectations imposed by the people close to him. Adaptive preferences are likely to be a real phenomenon of significance, as social environment certainly affect preferences and choices, and young people in particular may be inclined to be influenced by their circumstances. As noted above, Laukkonen (2018) provides evidence of those from less educated households being less likely to apply to highly demanded colleges. While this is probably partly because of credit constraints, it may also be the result of young adults from less educated households being shaped to prefer less demanding subjects, because of, for example, lower self-esteem and less educated parents setting other aspirations for their children.

Adaptive preferences raise difficult questions for normative evaluations of admissions procedures, for many normative benchmarks. Is maximizing adapted preferences welfare maximizing? Maybe college admissions procedures (among other mechanisms) should not consider welfare maximization at all, but, for example, justify prioritizing preference maximization as a requirement of respecting personal autonomy in decision making. Then we could say that it follows that people have a right to make mistakes in choosing their study paths, and mostly ignore the questions of what kinds of societal outcomes preference maximization may lead to. While this may be a tempting possibility (and the one usually adopted), it runs into problems in the case of adaptive preferences, as preferences corrupted by personal circumstances are hardly autonomous. Adaptive preferences may also lead to a serious misallocation of talent from the point of view of the society, which also confounds more general utilitarian objectives, and finally financing of the public sector.

Hausman and McPherson (2009) argue that preference satisfaction can be taken as a basis of welfare evaluation when two conditions hold. First, if people are self-interested in their preferences over the alternatives in question, then we can use people's preferences as evidence of what people believe will benefit them. Secondly, if in that particular choice situation individuals are good in judging what is beneficial for them, then we can use their

preferences as evidence concerning what in fact is welfare maximizing for them. This is what Hausman and McPherson call the evidential view of the connection between preferences and well-being: we do not need to equate preference satisfaction with welfare maximization, but we can take preferences as reliable evidence of well-being in the abovementioned circumstances. Clearly, adaptive preference may lead to failure of the second condition.

Also, we would first need to know the true preferences, which brings us to the issue of strategy-proofness. If the reported preferences do not equal the true preferences, we cannot even know what the applicants really (ex-ante) preferred, and we cannot make reliable welfare evaluations based on the reported preferences even if the two conditions of Hausman and McPherson (2009) obtain. Of course, as demonstrated in the above discussion, vulnerability to strategic behavior has a central place in the literature, and it is one of the most important contributions the matching model framework has for practical applications. However, real-life individuals and mechanisms are more complicated than their stylized model counterparts, and consequently strategic behavior has more scope in real-life admissions procedures than a naive analysis based on the college admissions model would suggest.

Another important issue is whether it is sufficient to consider preferences over colleges for evaluating applicants' welfare. In the context of school choice, the common practical requirement of strategy-proofness (Pathak, 2017) has made it evident that applicants tend to have strong preferences over the procedure itself and the costs caused by it. Quite understandably, the applicants do not seem to wish to partake in "admission games". For non-strategy-proof mechanisms, applicants need to spend time to determine the optimal application strategy (i.e. the preference list to state). Therefore, the simple matching models cannot take such costs into account, as they would require modelling preferences over broader outcomes, something closes to the social welfare maximization approach of mechanism design.

4.2.2 Preferences and excess demand

The structure of student preferences is what largely causes the costs of the admissions procedure. If student preferences aligned well with college capacities (i.e. if students

applied to different programs approximately in the proportion of the seats available in them), a much smaller proportion of the applicants would be left without a degree place and consequently, there would be no large costs related to the same applicants applying year after year. However, when some programs get far more applications than they have capacity to admit, and the applicants' preferences stay fixed in that they obstinately apply again and again to the same programs, the costs discussed above begin to mount.

This is a fundamental problem in the sense that no admissions mechanism that allows for a non-negligible chance of admittance to highly demanded programs for also others than first time applicants, as embodied above in criterion 3, can escape it. If admittance is determined on the basis of the matriculation examinations instead of entrance examinations, there may be reason to hope that the costs will be smaller, but they will remain substantial: the time not spent preparing for entrance examinations will be spent preparing for retakes of the matriculation examinations. If admittance was based on lottery, the applicants would spend years doing something else and waiting for that lucky draw. On the other hand, if the first-timer quota approached 100 percent, then admittance for others would be nearly impossible, and they would have to acquiesce with something else. However, this would amount to a breach of criterion 3. In principle, the policy maker could also assign students to colleges based on some centrally fixed priority criteria (success in past studies) without regard for student preferences, but this would breach criterion 1 (and produce very counterproductive incentives).

Because information plays such a huge role in preference formation, and many college programs find it difficult to fill their seats while others can admit annually only 5% of their applicants, the policy maker might hope to influence applicant preferences to steer the demand from the heavily contested programs to those facing weaker demand. This could be done by providing more information on different career possibilities for high school students: McGarth et al. (2014) report that increasing the information available to students before they make their higher education decisions and student counselling for college students seem to increase attainment rates. There is some evidence that providing information to students about the benefits of future education may increase their propensity to study more, at least in some settings (e.g. Jensen 2010; Oreopoulus & Dunn, 2013), but less on whether they can be influenced to choose specific career paths over others.

This is especially important given the high proportion of third year high school students still uncertain about their future education preferences (TAT, 2018). It can at least be hoped for that increasing information about different career paths, in conjunction with the widely varying difficulty levels of admissions to different programs, would help to channel demand to meet the (exogenously determined) supply conditions.

4.3 Adjusting supply to meet demand: a solution?

Instead of trying to adjust the demand side to meet the supply of higher education, the policy maker could solve the chronic excess demand faced by the higher education system by adjusting supply to meet the demand conditions, heavily increasing the supply of education in highly demanded fields, such as medicine, and correspondingly decreasing the number of degree places available in college programs that face lower demand. In practice, the government could implement this by its usual means of financial control. Of course, this would then make the question of an optimal admissions mechanism trivial, because degree places would not be contested.

Normatively, this could be based on two alternative judgements. Firstly, if we give a strong priority to satisfying applicant preferences, then naturally the optimal admissions mechanism is the one that gives everyone their stated first preference (which is clearly strategy-proof). Secondly, if the society sets as the objective the maximization of a general measure of social welfare, then satisfying student preferences can still be given a practical priority, if we believe it to be a very effective instrument for achieving higher economic performance.

Of course, this requires that the demand is reasonably constant from year to year, or changing at a reasonably constant rate, because adjusting supply to meet large demand fluctuations would be difficult in practice. However, maintaining the second argument would be very difficult also for other reasons.

First, as the Finnish higher education system is largely publicly financed, this would at least initially put a heavy burden on the taxpayers, at a time when the growing government deficit is already seen as a large problem. This is amplified by the fact that education in some of the more demanded subjects, especially medicine, are seen to be comparatively expensive to provide in an adequate manner. Of course, it could be argued that the current

investment in education is less than optimal, and radically increasing the financing of higher education and degree places would lead to higher output growth and higher tax income to balance the budget via increased productivity in the long run. However, the optimal level of investment in higher education is a contentious topic, and the effects of increased spending on productivity would certainly depend on its allocation between different colleges and the amount spend per one student.

Secondly and relatedly, societal preferences concerning the optimal mix and level of education and the consequent labor supply need not correspond to the one demanded by the applicants. While there could be overall welfare gains because of higher output and increased preference satisfaction, as applicants are provided higher education in the subjects they desire, the structure of education demanded need not be the one that maximizes output or any other measure of well-being: maximizing the preferences of the applicants might result in a country full of lawyers and doctors, but that might not be an overall outcome that anyone would prefer.

Of course, demand would adjust in the long run at least to some extent to the new market conditions. For example, increases in medical school intake would lead to more physicians in the labor market and consequently lower wages for them, which would likely help to decrease the demand for medical education. However, the resulting allocation need still not be socially optimal. The same may apply to the allocation of education that would result from a completely decentralized higher education sector, i.e. one where colleges would be completely independent from the policy maker both financially and in decision making.

Finally, as discussed in the previous section, the preferences of applicants need not be very definite or final. Preferences concerning different subjects can evolve over time as new information cumulates, and a new high school graduate is unlikely to have very good information on all the possible topics that could interest her. Somebody who regards medicine as her first choice might find out that seeing blood keeps making her feel nauseous. If switching between different programs was very easy because of high supply, it would lessen the incentives to persist in finishing a degree in a given subject, even though looking back later, the student could prefer to have finished the degree, despite of discomfort felt during the studies. McGarth et al. (2014) note that in some cases, open

access to higher education seems to be associated with lower graduation rates. Here there is a possible conflict between two aspects. On one hand, sometimes switching from one program to another might be for the best of both the student and the society, if the student is much more motivated and talented in the subject she changes to. On the other hand, because of the indefiniteness of preferences, switching from one college to another need not really be welfare improving.

The first two of the above points would make also the first kind of normative justification problematic, if the society values also the educational preference maximization of future generations and the capability of the state to supply them education was reduced by weakened economic performance. Still, as discussed above in section 2, it is noteworthy that in many European countries, a degree place in college is guaranteed for all eligible applicants. Of course, this does not yet correspond to the proposal above, because the undergraduate programs then tend to be much more general in curriculum, with the selection for more specialized education happening during the studies.

As discussed in section 2, the Finnish government aims to set the supply of education to the optimal level by considering sector-level labor demand and the targeted industrial structure, though it can questioned if it currently succeeds in picking the welfare-maximizing supply mix or if the policy makers, for example, do not take applicant preferences adequately into account. Of course, planning the supply of education centrally places high information requirements on the central planner.

4.4 Centralized versus decentralized college admissions

A recent strand of literature has strived to analyze game theoretically the functioning of decentralized college admissions markets, largely inspired by the American system. Che and Koh (2016) note that though the matching literature has seen a lot of research towards understanding the properties of matching algorithms used in centralized markets, and though there are studies that help to understand why some decentralized markets do not work well (e.g. Roth and Xing, 1994, 1997), it is not very well understood why many matching markets remain decentralized, and how to assess the welfare properties of decentralized markets relative to centralized markets.

It is outside of the scope of this study to examine these models in great detail, and in any case, the literature is still small. However, we aim to briefly conclude the results that have been obtained concerning the efficiency of a centralized clearinghouse relative to a decentralized market.

Che and Koh (2016) study a model of decentralized matching where two colleges with limited capacity compete for a mass of students, with colleges valuing two attributes in students: a score that both colleges value in the same way (e.g. a matriculation examination grade average) and a value that measures the college-specific capability of the student (think of entrance examinations and interviews), and they admit those applicants that are good enough on a weighted combination of those scores. However, while the colleges face no uncertainty concerning student abilities, they do not observe students' preferences, and their enrollment uncertainty depends also on the admissions decision made by the other college. This creates a situation where colleges will strategically admit students that the other college does not, by placing an excessive weight on the college-specific attributes of students. Because colleges have incentives to alleviate enrollment uncertainty, the model has also potential to explain why U.S. colleges often have a policy of preferring students whose parents attended the college, and why the colleges have a preference for students who show early interest to the college by partaking in the early admissions procedure, as analyzed also by Avery and Levin (2010).

Consequently, Che and Koh (2016) find that students who rank very highly on the common score can receive less admissions than those who rank worse on the common score. The resulting matching is both unstable and inefficient. In their model, a transition to a centralized matching conducted via the student-proposing deferred acceptance algorithm would bring about efficiency and stability but could make some colleges worse off than under the decentralized market structure.

Chade, Lewis and Smith (2014) analyze a somewhat similar model of decentralized college admissions, but they add frictions to the market: students find applications costly, and face uncertainty regarding how colleges rank their applications. Students' preferences are also homogenous in their model, and the application cost is the same for both colleges and all students. Unlike in the model of Che and Koh (2016), students then need to solve a portfolio choice problem, and colleges face no aggregate uncertainty but observe student

quality only as a noisy signal. Chade et al. find that in equilibrium, student-college sorting may fail, with worse students applying more aggressively to the better college and the weaker college applying higher requirements. However, they do not consider how centralization would work in their model.

Hafalir et al. (2018) study a model where colleges rank students based on their success in entrance examinations. As in Chade et al. (2014), there are only two colleges and students' preferences are homogenous. The cost a student pays for the entrance examination depends on the ability of the student. They compare equilibria of centralized college admissions, where students apply to all colleges, and decentralized college admissions, where each student applies to only one college. However, in both cases, the entrance examination is a common one, and colleges do not rank the same exam differently. It then can be seen to correspond to a matriculation examination but may still capture quite well the sorting that happens with decentralized entrance examinations, because colleges set their cutoff levels independently.

The model predicts that lower ability students prefer decentralized admissions while higher ability students prefer centralized admissions, and that student-college sorting can fail in decentralized markets but not in the centralized system. Interestingly, students can prefer the decentralized system, because centralized college admissions can lead to a higher effort exerted in equilibrium. This is intuitive in the sense that in the centralized system with common examinations, a student must compete against the whole pool of other students, while in the decentralized case, a student needs to compete with only those that applied to that college. As Hafalir et al. (2018) note, a definite answer depends on the utility loss assigned to the cost of the examination and the possible other benefits obtained from the study process.

Interestingly, Hafalir et al. (2018) run experiments to test the predictions of their model and find that many of the results agree with the model, for example, the decentralized system leads to less sorting by ability and more high-ability students are left unassigned. However, subjects exert higher effort than predicted, possibly reflecting high risk aversion, and actually exert more effort in the decentralized market.

Yenmez (2018) utilizes the matching-with-contracts framework of Hatfield and Milgrom (2005) to device a clearinghouse that utilizes the student-proposing deferred acceptance mechanism. The clearinghouse allows students to specify financial aid in their preferences, and they can commit to enroll, as in early admissions programs. He then derives the conditions on college preferences under which the sDA will implement a stable matching. Yenmez argues that such a centralized procedure would keep the desirable properties of decentralized college admissions, such as commitment (or signaling) and yield management, while avoiding unfairness and unraveling.

It is important to note that market centralization is a multifaceted thing that can come in many forms. Centralization can be in the form of having a single, centralized clearinghouse as the marketplace. In Finland, college admissions are largely conducted through a centralized clearinghouse, whereas in some countries, colleges look actively for students and students for colleges, without there being any centralized mechanism to arrange matches on the basis of stated preferences. On the other hand, when there is such a centralized matchmaking mechanism, the question of centralization in decision making arises.

If decision making is decentralized, as largely was in the Finnish college admissions previously, colleges can themselves choose their admissions criteria to select their preferred set of students from among those that apply. Around 750 American colleges also use a common application platform (Yenmez, 2018). The centralized marketplace is then merely an information device, which helps students to learn of the various colleges and makes the sending of multiple applications formally convenient, even if admittance can require costly investments in practice. It would seem likely that less well-established colleges would find it therefore beneficial, while more well-known colleges would find it harmful for their applicants to learn of other potential choices. However, insofar as the colleges are not required to homogenize their admissions criteria, it would seem that there is little incentive to stay out.

In a more centralized market, also decision making is centralized in that the policy maker sets tight constraints on the admissions criteria. Of course, there are always some constraints specified in the law, and even in a very centralized system the policy maker may prefer to leave some autonomy for colleges to decide on their criteria.

Centralized marketplaces and centralized decision making can occur due to willful participation, as is the case for the American doctors' residency match, or because the state enforces it, as is the case in the Turkish college admissions procedure. Willful participation requires that the participants cannot improve their outcomes by looking for matches outside of the system. Establishing a centralized system requires that even if the participants could benefit from arranging matches outside of the system themselves, the state has the ability and is willing to enforce participation. If the state cannot enforce participation despite of requiring it by law, ignoring the possibility of strategic behavior may lead to wrong conclusions. Roth and Shorrer (2018) consider a situation where the policy maker cannot or does not want to enforce participation in the centralized marketplace and analyze theoretically the conditions that the marketplace mechanism must satisfy for it to be safe for the participants to join the marketplace.

There is so far very little empirical work looking into the welfare effects of centralization relative to decentralization. Machado and Szerman (2019) use time variation in the gradual introduction of a centralized clearinghouse in Brazilian college admissions and report that it increased the assortative matching of students and colleges, with more application across geographical areas. There the centralization included abandonment of college-specific entrance examinations in favor of a common examination.

5 CONCLUSIONS

In this thesis, we discussed the characteristics and recent developments of the Finnish college admissions procedure, reviewed the relevant two-sided matching literature that concerns the design of a clearinghouse and finally considered the aspects that a policy maker must take into account when designing a procedure for college admissions, including a brief look at the literature on the functioning of a decentralized college admissions market. On this basis, we can make some conclusions. Regarding practical recommendations, it is of course clear that very little can be coherently said without fixing a social welfare function that specifies the values the policy maker puts to students' preferences relative to colleges' preferences (or the autonomy of universities), among other things. Policy makers would do well to clearly specify the objectives they pursue and the trade-offs that they are willing to accept.

Both theoretical literature and empirical experience suggests that the student-proposing deferred acceptance algorithm is the best way to conduct the matchmaking in a centralized clearinghouse, when fairness of the outcomes with respect to the admissions criteria is valued highly and there is little reason to be concerned that colleges engage in strategic behavior. These considerations are likely to be satisfied in the Finnish context: it would probably be seen as unacceptable that an applicant with a higher score would lose a place to someone with a lower score, and with the control that the state exerts over colleges in both capacity and admissions decisions, it would seem unlikely that they could manipulate the mechanism to their advantage[6]. The results concerning the large market behavior of the mechanism lend support to this.

The student-proposing deferred acceptance mechanism is the mechanism that best satisfies students' preferences subject to the requirement that the students' priority rankings at schools are not violated. That it is strategy-proof for students is another important advantage of the mechanism: first, for ensuring that the said efficiency and fairness properties hold with respect to the actual preferences, secondly, because manipulable mechanisms may put applicants from certain backgrounds to a weaker

[6] Though we conjecture that there is at least a theoretical possibility that colleges could set the weighting of matriculation exam grades in a way differing from their real preferences to gain a preferred set of students.

position, and thirdly, because applicants are likely to dislike mechanisms that force them to spend time on deciding their optimal strategy. Welfare of applicants is likely to depend also on the procedure of the mechanism, not only their assignment.

Indeed, the Finnish clearinghouse uses the student-proposing deferred acceptance mechanism (OKM, 2016). However, strategy-proofness of a mechanism is fragile. As shown by Dur et al. (2018), a deferred acceptance algorithm mechanism where applicants are given extra points for listing a college higher on their reported preferences is not strategy-proof. Such a system is still in place in Finland for some colleges, at least for some medical schools (Lääketieteelliset.fi, 2018). Moreover, the procedure allows students to list only six choices in their reported preferences, which Haeringer and Klijn (2009) show to ruin strategy-proofness. Removing these peculiarities would help in making the mechanism strategy-proof, probably with little cost. First timer quotas currently used could be analyzed formally using models of dynamic matching, but such a review is out of scope here. It seems likely that such quotas increase the propensity to take gap years but decreases the proportion of students who drop out after they acquire a seat in a preferred college.

Even larger problem for the strategy-proofness of a mechanism is the presence of college-specific entrance examinations. College-specific entrance examinations force a student to face a portfolio choice problem on the different entrance examinations, meaning that preferences must be weighed against the probability of admittance, much like we saw with the Boston mechanism. As a result, a student may take entrance examinations in and report as preferred colleges she does not really prefer to others. It also leads to a situation where a college regards as acceptable only a very minor subset of all students (i.e. those we took the entrance examination). The issue of strategy-proofness is then not so much about whether a student has incentives to report her true preferences to the mechanism, but about whether she takes entrance examination for the college she prefers. The centralized clearinghouse serves then merely as an information device and convenient application platform.

However, as is the case with college-specific entrance examinations, using a common entrance examination does still not make it a strongly dominant strategy to reveal true preferences (only weakly so), because students still do not gain anything by listing

choices they do not believe they have any chance of getting admitted to. This must be kept in mind when using the reported preferences for analyzing demand for different colleges and subjects. Very competitive colleges are likely to be even more strongly preferred than it seems like. Some writers analyze the proportion of students that have received their first reported preference as indicative of match quality (e.g. Ahola & Spoof, 2019; OKM, 2016), but this is dubious with no knowledge of true preferences.

Still, we conjecture that a system with a common entrance examination is more strategy-proof, because then the student is not faced with a portfolio choice problem regarding the set of different entrance examinations[7], and the possibility of admittance is then never quite zero, as it is with colleges for which one does not take an entrance examination. The central distinction seems to be whether the application cost is common or college specific. The theory of two-sided matching cannot yet say much about such issues, though there is some recent work that extends the college admissions model to a case of common entrance examinations (e.g. Abizada & Chen, 2015; Perach & Rothblum, 2010). Applicants may try to manipulate even a strategy-proof mechanism, which makes it clear that they should be presented with clear information on the procedure, and that the policy maker must try to retain the trust of the general public.

However, there are several thorny questions which the policy maker cannot escape. It is evident that no mechanism design solution can by itself solve the problem of excess demand for certain colleges and shortage of demand for others, and the consequent long waiting times for access to higher education. If preferences of applicants differ from the supply of education deemed optimal by the policy maker, potentially also in the sense that there are more applicants than the policy maker considers it optimal to give access to higher education to, there will be mismatch between demand and supply and long waiting lists as a result. Of course, the larger the mismatch is, the more there will be applicants incurring costs but being left out of college, and it is then all the more important that the admissions mechanism works efficiently and with low costs.

[7] Of course, with different weightings for the matriculation examination grades in different colleges, the student must then choose optimally the investment made in studying for the matriculation examination… A matriculation examination for which different colleges use different weightings is not quite a common entrance examination.

The transition from a system of college-specific entrance examinations to admissions based on matriculation examination (i.e. a common entrance examination) may help to reduce the costs of the admissions system to some extent, because it reduces the costs incurred by colleges in organizing the entrance examinations. However, as students have then stronger incentives to retake the matriculation examination and therefore cause additional costs in the high school sector, the overall effect on costs of the admission procedure is left uncertain. It is sometimes argued (e.g. OKM, 2016; Pekkarinen & Sarvimäki, 2016) that a common entrance examination provides a real possibility of applying to multiple competitive colleges in the same year, consequently leading to a better match of colleges and students. While this seems likely, the size of this effect depends on student preferences: whether or not they will accept their secondary choices or apply again in the future for their first preference. There is already some evidence that retaking of matriculation examinations has considerably increased (Yle, 2019 August 11). Analyzing the overall effect on costs is an important topic for future research.

As indicated by the model of Hafalir et al. (2018), students may actually exert more effort in a system with a common entrance examination, meaning that there may be more studying time spent preparing for the common entrance examination than would be spent on the college-specific examinations. However, the policy maker may well prefer that outcome, as understanding of high school material may be seen as insufficient otherwise, while the knowledge learned studying for college-specific entrance examinations is seen as largely useless for most applicants (e.g. OKM, 2016). The matriculation examination grades of previous years are also usable in future admissions, and therefore the work of previous years is probably not lost so much as it is with college-specific entrance examinations.

College-specific entrance examinations could still organized for those who have not completed a matriculation examination (or those who took their matriculation examination a long time ago), but should then be strictly reserved for them, as is already done in some colleges. Again, how many places are reserved for them requires a decision regarding how large a weight the policy maker assigns to the well-being of those who want to change their career path.

Many colleges may prefer to keep entrance examinations, because it enforces students to learn some of the subject material in advance. However, as in the models of Che and Koh (2016) and others, the admissions criteria set by the colleges need not be a one that maximizes the satisfaction of applicant preferences. The policy maker must decide on the weighting it gives to the autonomy of universities relative to student preferences. Learning the subject material also provides an introduction to the topic, which can lead a student to reassess her motivation.

While learning one's preferences is certainly too late at that point, it is fathomable that easier access to highly selective colleges may lead some students who performed very well in the matriculation examination to make choices that are soon regretted. It is an interesting and important question for future research whether the reform leads to more students changing their major after the first year. One obvious remedy to the problem is improving the information provided to high school students about possible college choices, preferably in a way that makes the students study the subject material in some way. However, if such college courses offered to high school students are given any large role in admittance, they will simply turn into very expensive college-specific entrance examinations.

Some also assert that a college-specific entrance examination is a better way of revealing information on students' capabilities, and while this is certainly true for some subjects (e.g. a school of musical arts), there is no evidence of it holding true more generally (Ahola & Spoof, 2019). In the end, the potential benefits need to be weighed against the costs. It is also claimed that entrance examinations help less popular colleges in yield control, but again, evidence is sparse.

Matching colleges and students based on secondary education qualifications also means that choices made earlier in life have a larger role in deciding admission to higher education. While this is beneficial for encouraging good performance in high school, it is unclear what effect it will have on socioeconomic equity. As shown by Laukkonen (2018) and others, the socioeconomic status of parents may substantially affect the choice of education in the system of college-specific entrance examinations, for which costly preparation courses have been identified as one contributing reason. However, as Marks, Cresswell and Ainley (2006) discuss, system where students must lock their career path

earlier tends to show stronger correlation between socioeconomic status and student achievement. This is also another reason for not taking the satisfaction of reported preferences as an indicator of welfare without qualifications.

We did not delve deeply into issues concerning decentralized college admissions, but while there is not much empirical research analyzing the effects of centralization, theoretical work seems to suggest that decentralized markets may not produce matchings that are efficient with respect to preferences of students. There is also well-known research (e.g. Roth & Xing, 1994, 1997) showing that some decentralized matching markets may be prone to unraveling, but it is outside of the scope of this study to consider the conditions under which that may happen. In the case of college admissions procedure like the Finnish one, this would mean that some colleges would decrease their commitment to the central marketplace and start searching for future students at earlier dates, before the students have even completed their matriculation examinations (much as in the case of the American early admissions procedures). We have not observed much of such behavior in Finland. One important advantage of a centralized mechanism with publicly known and objective admissions criteria is that it is likely to be less vulnerable to corruption and perceived as more fair. The recent scandals in the American college admissions highlight this point.

As further topics for future work, it would be interesting to analyze the structure of labor supply that would result from setting the supply of education to more closely match the demand of education. More work on the relation between entrance examination scores and consequent academic performance would be beneficial, as would studying how the relation between socioeconomic background and academic attainment evolves during changes in the admissions procedures. More theoretical research on the relation between centralized and decentralized matching markets is also required, including a full characterization of the conditions under which a centralized clearinghouse would bring about a higher preference satisfaction for the students. It is also evident that analyzing college admissions models with exogenous college preferences is often insufficient.

Rubinstein (2006) believes economic theory to be of very little practical use, at best a perfectionistic endeavor and at worst, a collection of fables with a morally corrupting influence on students of economics. While practical applications, such as the one

discussed in this work, highlight the contrast between the messiness of real mechanisms and elegant theory, it seems that at least the market design literature has found a way to make economic theory useful.

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