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Mechanisms, Preferences, and Heterogeneity in Matching Markets

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Many things in life are about finding matches in two-sided markets. One side of the market hands in the proposal, but the other side has to accept it to form a match. Finding a job implies that you prefer the job/company/boss/colleagues and they have to prefer you back. Finding friends implies that both sides mutually like each other. And as in the marriage market introduced by Gale and Shapley, love is a matching market as well. Nevertheless, matching theory normally does not talk about how the markets are formed. Where do all the people of the other side come from? Why do they form the preferences like they do? So, I am very lucky to say that the matching market of life has worked quite great for me over the last few years. I am very happy that I was and still am supported by a couple of people. Without them I am sure that I would not have made it to this point.

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Paderborn, December 2019 *Nadja Stroh-Maraun*

Contents

CHAPTER 1 Introduction

Since the publication of Gale's and Shapley's seminal paper in 1962 the theoretical, empirical and experimental literature on matching is growing in economics, mathematics and computer science. Additionally, several real-life problems have arisen and matching experts have been asked to design and redesign matching mechanisms in various fields such as the allocation of doctors and hospitals in the U.S. or the assignment of children to schools in New York, Boston, New Orleans and other cities around the world (e.g. Sönmez & Ünver, 2011). Consequently, in 2012, the Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel was awarded to Alvin Roth and Lloyd Shapley "for the theory of stable allocations and the practice of market design" (NobelPrize.org, 2012).

Nevertheless, the matching literature is far from complete. Whereas the original theoretical model by Gale and Shapley was quite simple, a group of men and a group of women having preferences over the other side, it relied on some crucial assumptions such as homogeneity of agents or independency of the individuals' preferences. Since then, a rich and insightful literature emerged in the following decades, proposing other and new matching mechanisms and discussing them in detail, several of these assumptions were still not dropped. This dissertation fills the gap here and shows what happens to matching markets if central assumptions of the traditional matching literature do not hold any more, especially due to the emergence of new technologies and, therefore, large markets.

Before going into details here let us take a step back. To discuss the impact of new technologies on matching problems we first have to think about how matching markets are characterized. On markets, scarce resources are allocated.

Very often this is done with the help of price mechanisms. Imagine you want to buy some fruits and go to the local farmer market. If you are willing and able to pay the signalized price, the fruits are yours. Especially, it does not matter if the selling farmer likes you or not. If you hand over the money, the farmer hands over the fruits. Otherwise, another consumer might have the possibility to purchase them. Nevertheless, this price mechanism does not work in all sorts of markets. Imagine the following situation in which colleges have a limited amount of seats they offer to potential students. To fill these seats they could just set prices until the market is cleared and all students who are willing to pay this price are granted a seat at this college. Of course, this scenario does not feel right as two problems occur immediately. First of all, colleges are not necessarily interested in the students who are willing and able to pay the price, like a farmer would be, but only in the bright ones. Second, politically a price mechanism would be difficult to implement as poorer students should get the possibility to study as well. Instead of relying on prices here, it seems natural to use the agents' preferences to find an allocation. Colleges are interested in good, bright students. Students prefer colleges that offer an interesting study program or have a good reputation. The allocation in this market should somehow take these preferences into account. Thus, the first characteristic of matching markets is that no prices are used to allocate the goods or services. Instead, preferences are taken into account. There is a second important characteristic of matching markets. Agents trade indivisible goods. In the case of the college admissions, each student wants to study at exactly one college. There are various examples for matching markets and these markets become even more important today due to new technologies.

Considering the new possibilities that arise from the growing development in IT markets, an example of a matching market or allocation problem occurs in the context of the CRC 901 on the so-called on-the-fly market. There a consumer asks for an IT service that fulfills his or her special, individual needs. This good now needs to be composed immediately out of a set of elementary services by an intermediary who buys the products from different producers or sellers. Additionally, the on-the-fly market is typically realized on a platform that is provided by a special market provider. Existing platforms for IT markets are for example the Apple App Store or the Google Play Store. One question is how to allocate consumers and intermediaries as the latter has a limited amount of time and resources to work on an order. How should we allocate intermediaries and sellers as each of the sellers only have limited resources and have access to only a fraction of all available elementary services? How should sellers decide upon their portfolio of elementary services? And last but not least how can the elementary services be composed to fulfill the consumers' needs given that also the services are scarce resources?

This example also gives an intuition that markets can become quite large nowadays. Now imagine a large, more complex matching market in our college setting. Perhaps, there are some students who want to study part-time. Or perhaps there are some students who are disabled and need special treatment and more supervision such as more time to write an exam. Thus, students become *heterogeneous*. In a small market, these cases might be very rare and thus, negligible. However, in large, flexible markets this problem becomes very relevant.

Another striking problem in large markets in addition to the heterogeneity of students, or more general of agents, is *how to form preferences*. If the possibilities are manifold, it becomes almost impossible to know everything about all choices. A student looking for a seat at a university or college in Germany had to choose between 426 possibilities in the winter term 2018/19 (Statistisches Bundesamt (Destatis), 2019). It is not very likely that a student knows all these 426 universities so well that he or she can formulate preferences. The same is true for the colleges. They of course do not know all the students. Nevertheless, preferences have to be formed and a matching has to be found.

Coming back to our on-the-fly market in which it is rather obvious that these problems also play crucial roles. Consumers are heterogeneous in their demand which might lead to different efforts an intermediary has to spend on an order. As the market is quite large, it is also very likely that the consumers do not know all the different intermediaries or at least do not have the information on who is best suited for their special order.

This thesis examines what happens in matching markets when there is heterogeneity or not enough information to form preferences on a theoretical and empirical level. We examine how incomplete information influences the behavior of agents in a mechanism that is not strategy-proof especially if these agents are heterogeneous (Chapter 2) and how heterogeneity affects the functioning of well-known matching mechanisms and their results (Chapters 3 and 4). Afterwards, we focus on the attempts to deal with incomplete information or more precisely how to form preferences if not all the agents are known. First, one way of dealing with it is to react to signals you received from the other market side. In the particular case, we are focusing on schools that observe which students rank them quite high and reciprocate these rankings (Chapter 5). Afterwards we examine whether it is possible to rely on observable criteria when formulating preferences. This empirical study takes place in the slightly different context of matchmaking in online games, which can also be interpreted as a coalition formation problem (Chapters 6, 7 and 8).

In the remainder of this introduction we will now firstly introduce the theoretical, empirical and experimental background of matching markets (Section 1.1) with heterogeneous agents (Section 1.2) and the theoretical and empirical background of forming preferences based on objective criteria (Section 1.3) before outlining the research questions and results of this thesis in greater detail (Section 1.4).

1.1 Matching Markets - Between Theory and Practice

According to Al Roth, winner of the Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel 2012, “matching markets are markets in which you can’t just choose what you want (even if you can afford it), you also have to be chosen” (NobelPrize.org, 2012). Especially, in these matching markets like “in lots of markets, prices don’t do all the work” (NobelPrize.org, 2012). The attention to matching markets arose in 1962 when Gale and Shapley first introduced the very famous marriage market, in which a set of men and a set of women are looking for a partner of the opposite set to marry. Both sides have preferences over the other side as it is assumed that no one is indifferent about the partner choice. Gale and Shapley were looking for a stable matching. This is quite intuitive, as stability ensures after a matching is found and all couples are formed that no new couple can form that is not married or matched to each other yet but would prefer to be matched to each other. To phrase it differently, stability ensures that no one can find an affair to cheat on their partners. Gale and Shapley showed that there is always a stable outcome and they also gave a procedure to find one, the deferred acceptance algorithm (DA) (Gale & Shapley, 1962). In the deferred acceptance algorithm either men or women propose to the other gender. If men propose, the result is the men-optimal stable matching and the other way round. Unfortunately, stability comes with a cost as there is no matching mechanism that yields a stable and strategy-proof outcome although strategy-proofness can be assured for either men or women if the deferred acceptance algorithm is used (Roth, 1982a). Gale & Shapley (1962) used the results of the marriage problem to solve the more general case of the college admissions problem where students are looking for a seat at a college and colleges are offering amounts of seats. This market is close to the example that is mentioned in the very beginning of this introduction. Fortunately, the main result of the marriage market carries over: There is always a stable outcome and it can be found with the help of the deferred acceptance algorithm. The outcome is either the student-optimal stable matching which is weakly preferred by the students over all stable matchings or the college-optimal stable matching which is weakly preferred by the colleges (Roth & Sotomayor, 1990). Again, there is no matching mechanism that yields a stable and strategy-proof outcome (Roth, 1982a). By using the student-proposing deferred acceptance algorithm, truth-telling is a weakly dominant strategy for students. Unfortunately, this is not true for colleges in any stable mechanism. Therefore, although the two problems are closely related, the marriage and the college admissions problem are not equivalent (Roth, 1985). Gale & Shapley (1962) assume that colleges have preferences over individual students. This assumption might be relaxed to also account for preferences over groups of students as long as these preferences are responsive or substitutable (Roth & Sotomayor, 1990). Both conditions ensure that a student is not only preferable as long as another specific student is also assigned to the school. If preferences are responsive, the preferences over groups can be related to a preference list over individual students. In 1984, Al Roth made an interesting discovery as he found out that the deferred acceptance algorithm was already in use in the NRMP, a clearinghouse in the U.S. to match medical interns to hospitals (Roth, 1984). Both models, the marriage market and the college admissions problem, are two-sided problems. There are two disjoint sets of agents who want to be matched to one or more agents of the other side. If both sides are looking for exactly one match, such as in the marriage market, we talk about one-to-one matching. If one set of agents also accepts more than one agent of the other set, like colleges offer seats for a couple of students, we talk about many-to-one matching markets. Economically, in several cases we actually deal with many-to-one situations as firms, for example, often look for more than one worker, intermediaries can supply multiple consumers with IT services and also some applications in the real world, such as the already mentioned NRMP, deal with many-to-one matching markets. All these markets share the same characteristics as the well-known college admissions problem. Therefore, this thesis uses the college admissions problem to examine heterogeneity and the forming of preferences on two-sided many-to-one matching markets.

In contrast to two-sided problems, many matching markets actually are one-sided, such as housing markets where a number of agents own houses but want to reassign them on the basis of their personal preferences (Shapley & Scarf, 1974). Shapley & Scarf (1974) proposed an algorithm, Gale's top trading cycles algorithm, that finds a matching in the housing market. Actually, this matching is the unique one in the core of the housing market (Roth & Postlewaite, 1977). The algorithm itself is strategy-proof (Roth, 1982b).

One- and two-sided matching problems seem to be very distinct at a first glance. This is far from being adequate. In 2003, Abdulkadiroğlu & Sönmez introduced a hybrid model called school choice. This model describes a one-sided matching market in a setting that is quite similar to the college admissions problem: Students shall be assigned to schools. Students are treated as agents as in the college admissions model. The big difference is that schools are treated as objects. Thus, their role is comparable to the houses of the one-sided models. But at the same time, schools generate a ranking over individual students comparable to the colleges in the college admissions problem. The big difference here is that the priorities, the schools have here, are based on some objective criteria, such as walking distance or siblings already attending the school. Therefore, they are not expressions of a free will but of institutionalized ranks. A student who lives within walking distance should be prioritized over a student who lives quite far away. In contrast to the colleges in the two-sided model, schools always state the true priorities as they do not react according to incentives. The introduction of this hybrid model now introduces new possibilities to find an outcome. As only the students are treated as agents in school choice models, solution concepts focus on them. A matching can either result in a fair outcome or in a Pareto efficient one for the students. The fairness condition is (again) stability as it eliminates so-called justified envy and can be found with the help of the student-proposing deferred acceptance algorithm. A Pareto efficient outcome can be found with the top trading cycles algorithm (TTC), based on Gale's top trading cycles algorithm. Both algorithms are strategy-proof for the students (Abdulkadiroğlu & Sönmez, 2003). As we can see, school choice is a hybrid problem also in terms of the solution concept. Depending on the concrete model or application one of the two solution concepts might be beneficial. The school choice model is closely related to student placement (Balinski & Sönmez, 1999) where the priorities of all schools are determined via a central exam for all students. In this context, the elimination of justified envy is to choose as the test results have to be respected. If a matching is Pareto efficient, the schools' priorities can be interpreted as opportunities. The higher the student's ranking at some particular school, the higher his or her chance to be matched to a preferred school. Thus, priorities are violated to find an efficient outcome. School choice is particularly interesting as many real-life applications actually rely on this framework. Additionally to student placement, which is used in Turkey (Balinski & Sönmez, 1999), school choice models are used in many U.S. cities such as New York City (Abdulkadiroğlu et al., 2005a), Boston (Abdulkadiroğlu et al., 2005b) and New Orleans (Abdulkadiroğlu et al., 2017) where the deferred acceptance algorithm is used nowadays. Next to the two proposed algorithms there are several more mechanisms used in real-life, not all of them yielding economically reasonable allocations. The most famous alternative is the so-called Boston (school choice) mechanism (BM) or immediate acceptance mechanism which was used in Boston before the system was redesigned by Abdulkadiroğlu et al. (2005b). The Boston mechanism is neither stable nor Pareto efficient and not even strategy-proof (Ergin & Sönmez, 2006). Nevertheless, this algorithm is still used in practice, e.g. at Paderborn University (cf. Chapter 2). The school choice model has various advantages. It focuses on one market side, the students. Therefore, in contrast to the college admissions problem, strategy-proofness can be guaranteed. School choice models are widely used in theory and practice. A stable or a Pareto efficient outcome can be found which offers greater flexibility. This is particularly interesting in the on-the-fly market where the platform on which consumers and intermediaries meet is provided by a central authority or a big company with own interests, a so-called market provider. School choice gives some market power to the central clearinghouse or market provider by deciding which of the two properties should be fulfilled and which algorithm is to be used. Thus, this thesis also uses the school choice problem to examine heterogeneity and the forming of preferences on matching markets.

A broad categorization about the one- and two-sided matching markets described above can be found in Figure 1.1. The two models that are discussed in this thesis in more detail are highlighted in gray. Note that this categorization is far from complete as it focuses solely on the models most relevant for this thesis.

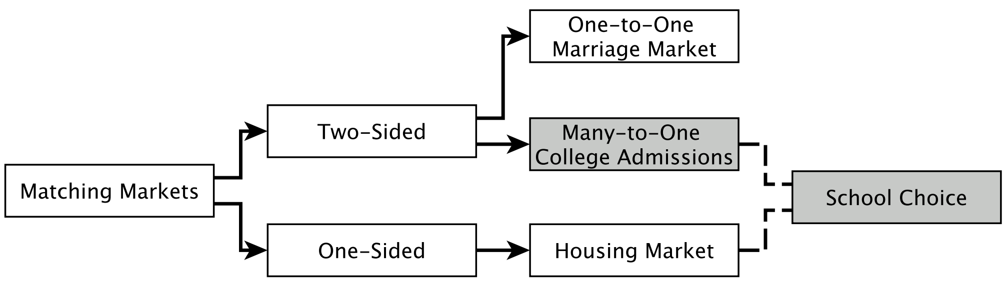

Figure 1.1: Categorization of Different Matching Markets

1.2 Matching Markets with Heterogeneous Agents

As already mentioned before, although matching models are widely studied in various scientific fields, homogeneity and complete information are crucial assumptions in the literature. In this thesis we study the consequences of the lack of them to various settings in college admissions and school choice problems. In classical school choice and college admissions problems, students are assumed to be homogeneous concerning their need for capacity, care and supervision. Therefore, every student is looking for exactly one seat at one school or college. We drop this assumption by introducing students' weights. If a student needs more care or supervision than another student, he or she has a higher weight. Thus, instead of always needing exactly one seat at a college or school, a student might need one and a half or even two seats. This model is not studied very intensively in the literature so far. There are few papers dealing with this problem, also known as matching markets with sizes (Biró & McDermid, 2014). In such a market, stability can no longer be assured (McDermid & Manlove, 2010). A related problem, matching with couples, was introduced by Roth (1984). We study the consequences of the introduction of weights in college admissions and school choice problems in the Chapters 2, 3 and 4.

1.3 Preferences and Objective Criteria

Incomplete information was introduced to matching markets by Roth (1989) who showed that truth-telling might still be a dominant strategy in a setting where agents only have information on the overall distribution of the others' preferences. Ehlers & Massó (2015) and Chen & Pereyra (2019) analyzed the consequences of incomplete information to a stable mechanism theoretically and experimentally, respectively. Incomplete information was also examined experimentally in a school choice setting; the Boston mechanism performs better with more information than with little information, whereas incomplete information is not relevant for the performance of the deferred acceptance algorithm (Chen & Sönmez, 2006; Chen et al., 2016a). Nevertheless, empirical results were still missing before. Therefore, Chapter 2 deals with the question whether students misrepresent in an application of a school choice problem and if they manage to improve their outcome. As we see, agents react to incomplete information but often fail to improve their outcome. Additionally, to deal with the lack of information on who actually fits best to a school or college, this side of the market might react to the students' behavior or signals. In some districts in France in school choice, schools assign points to students who have ranked that school first (Hiller & Tercieux, 2013). In the UK, the so-called "first-preference-first" mechanism was widely used before banned in 2007 (Pathak & Sönmez, 2013). Here schools were allowed to adjust their priorities to the students' preferences. We deal with the theoretical consequences of these adjustments in Chapter 5.

Another possibility for schools and colleges to deal with incomplete information is to base the ranking on objective criteria. This approach is similar to the idea of priorities that are based on objective criteria used in school choice problems. If the number of agents become very high, it becomes literally impossible for single agents to know everyone else in the market. Thus, it becomes impossible to formulate complete preferences over the other market side. We make use of the idea of objective criteria to form priorities or in this case preferences. The objective criteria in school choice are used to form the schools' priorities, e.g. schools prefer students who live in walking distance. We answer the research question whether it is possible to also form (more complex) preferences out of some objective criteria. In a two-sided matching market, both sides bring their own needs and characteristics without being able to express preferences over the other side directly. Therefore, a score or fitting quality for each agent may be estimated with the help of an empirical analysis. This idea is closely related to the approach by Bansak et al. (2018). They analyze another well-known matching market known as refugees matching where asylum seekers should be allocated to countries or cities. The authors estimate integration scores for asylum seekers in different geographical areas to form preferences for all asylum seekers and areas based on the likelihood of successful integration.

In refugees matching institutions play a crucial role similar to the school choice setting. Therefore, objective criteria can be found quite naturally. Asylum seekers need for example housing, jobs and slots at local schools. We want to find out whether it is also possible to find objective criteria in a market that is based on personal tastes. Such a market can be found in online-multiplayer video games. Whether a player has fun in a game depends on his gaming experience. And this experience depends on his teammates and opponents. Thus, this market is suitable to answer our question. Additionally, matchmaking in video game research is already well-established. In multiplayer online games new players need to be assigned to already existing teams, groups or game rounds (Delalleau et al., 2012). Most authors try to balance a game by matching players according their skill levels (Véron et al., 2014). So, in a first step, the skill levels are assessed. In a second step, preferences are drawn from these levels in such a way that very similar skill levels are preferred over more heterogeneous ones. This step is referred to as “matching” or “matchmaking” in this literature. The allocation of players to existing rounds is not directly considered in this stream of literature as it is assumed that players enter the game sequentially, which makes allocating individual players to the best-fitting round a more straightforward process.[1] To learn more about preferences and to test whether the fixation on skill level is correct we use data collected from a popular multiplayer online video game. We want to match new players to an existing team by interpreting the problem as a one-sided matching market, as we treat each team as an object. Thus, new players are looking for exactly one match each and a number of teams have free capacities for additional players.[2] The results of this analysis can be found in Chapters 6, 7 and 8.

[1] To adhere to the terminology, we also use the term “matching” in Chapters 6, 7, and especially in Chapter 8, although technically we only form preferences with the help of a so-called fitting quality.

[2] We could also interpret the problem as coalition formation here by treating all players as individual agents.

1.4 Outline

In the following chapters we analyze what happens if we drop the assumptions of homogeneity or complete information. In *Chapter 2. Matching Strategies of Heterogeneous Agents under Incomplete Information in a University Clearinghouse* we empirically analyze the behavior of students at Paderborn University in a school choice problem. Students who want to write their theses are allocated to supervisors via a clearinghouse at the Faculty of Business Administration and Economics at Paderborn University, where a variation of the Boston school choice mechanism is used. The students are heterogeneous as they differ in the type of thesis, Bachelor or Master. Supervising a Master thesis needs more time and effort than supervising a Bachelor thesis. Therefore, Master students need more than one seat at a supervisor. We denote that by Master students having a higher weight. Additionally, we deal with incomplete information. The students know their preferences but they do not know the other students in the clearinghouse, the other students' preferences or the supervisors' priorities. We analyze the students' behavior with the help of two different data sources, the data derived from the clearinghouse itself and data from a voluntary survey among the students who participated in the clearinghouse. We find that over 74% of students misrepresent at least one of their preferences. This is in line with the theoretical prediction that the algorithm used is not strategy-proof. Nevertheless, students are not necessarily able to improve their outcomes. This is due to two different factors. Partly, this is due to incomplete information. Additionally, we observe that some students misrepresent their preferences only if they believe that it is advantageous for them and otherwise state their preferences truthfully, so-called sophisticated students, whereas another group of students do not act in this consistent manner and, thus, is naive. This notion of sophistication is based on the theoretical definition by Pathak & Sönmez (2008). Sophisticated students actually reach significantly better outcomes than naive students. Thus, naive students are exploited by sophisticated students in an incomplete information setting.

Before trying to overcome the problem of incomplete information, we focus on the heterogeneity of students in more detail first. We model a college admissions problem with heterogeneous agents, meaning that students have different weights, in *Chapter 3. Stability in Weighted College Admissions Problems*. We show that if all colleges strictly prefer students with a specific weight over students with another specific weight, a stable outcome can always be found by applying a sequence of deferred acceptance algorithms. Nevertheless, in the general model, stable outcomes might not exist (McDermid & Manlove, 2010). To find a stable matching, if it exists, we propose a new algorithm, the deferred acceptance algorithm with gaps (DAG). It results in stable matchings if existing and cycles otherwise. Moreover, we show how to restore stability by increasing or decreasing the schools' capacity.

In *Chapter 4. Pareto Efficiency in Weighted School Choice Problems* we are the first to model a weighted school choice problem. This differs from the model in the previous chapter as in this one-sided market stability or Pareto efficiency can now be considered. As we see in Chapter 3, the existence of stable matchings is not ensured. This result carries over to the school choice setting. Therefore, we focus our analysis on Pareto efficiency. We propose a variant of the top trading cycles algorithms, the weighted TTC or WTTC, which is strategy-proof and yields a Pareto efficient outcome. Thus, the TTC is robust towards the introduction of weights. Nevertheless, the incorporation of weights comes with a cost as it is more complex to guarantee each student a seat at a school with the WTTC, because the model introduces a trade-off between weights and priorities.

After focusing on heterogeneity we come back to incomplete information at least indirectly. In the last chapters of this thesis we discuss how preferences can be formed if information is incomplete. This is especially the case if the market is very large and agents are therefore not able to form preferences directly as they do not know the other market participants. In *Chapter 5. Outcome Equivalence in School Choice with Reciprocal Preferences* we analyze what happens if the schools' priorities in a school choice model or the colleges' preferences in the college admissions problem are formed on the basis of the students' preferences. This "first-preference-first" manner can be found in France or the UK, for example, to overcome the lack of information on which student fits best to a certain school or college. We show that under this assumption the Boston school choice mechanism, the student proposing deferred acceptance algorithm and the top trading cycles algorithm all generate the same outcome. Particularly, all three mechanisms with reciprocal preferences are manipulable.

Basing preferences and priorities on the other market side's preferences does not yield a desirable outcome. Therefore, in a last step we focus on forming preferences on the basis of objective criteria. More precisely, we want to match players to existing rounds or teams in a multiplayer online-game. As mentioned before, we can interpret this setting as a two-sided matching market. New single players arrive in the market and want to be matched to an existing round that they prefer. The teams in the existing rounds also have a joint, single preference over the new players. Unfortunately, both sides are not able to form the preference lists as they do not know the other side of the market. Consequently, we try to find objective criteria on both sides to form preferences. In *Chapter 6. A Duration Model Analysis of Consumer Preferences and Determinants of Video Game Consumption* we want to learn what these objective criteria are. To do so we identify the specific, observable determinants of variations in the aggregate amount of time a player or consumer remains engaged with the online game with the help of an empirical analysis. We estimate duration models on the basis of data from a popular online video game that includes historic behavioral information for 1,408 consumers participating in 728,811 unique rounds of gameplay. We find that the main determinants are the experience and skills a player has in the game, the amount of variety a game offers and also the player's demographics.

In *Chapter 7. Variety in the video game industry: An empirical study of the Wundt curve* we focus our analysis of the objective criteria that determine the players' and groups preferences on the amount of variety in the game by using the same dataset as in Chapter 6. We see that players value a certain amount of variety. Nevertheless, the player's utility of variety follows an inverted-u-shape. Thus, there is an optimal amount of variety.

We conclude our analysis of the players' preferences by actually formulating them in *Chapter 8. More than skills: A novel matching proposal for multiplayer* *video games*. We analyze a dataset from a popular online multiplayer game that includes historic behavioral data of 6.9 million players participating in 862,664 unique game rounds. Actually, the dataset used in the two previous chapters is a subset of the dataset we use here. We find that players prefer being matched to a group that is homogeneous to his or her own skill level, also homogeneous according to some complementary attributes such as the age or home country, but heterogeneous among the inherent attributes of the game, which indicates the variety of the game. With these results we are able to form preferences by a three-step procedure.[3] Where the first two steps identify the acceptable rounds or teams of a player, the last step formulates a so-called "fitting quality" to rank the acceptable rounds. Thus, the result of our analysis is a preference list of a player over all available game rounds.

Before we proceed with the presentation of the seven main chapters, we would like to make a final remark. The following chapters were written as independent research papers. Therefore, they might vary slightly in terms of terminology (especially in Chapter 8) and notation. Also, there might be some overlap especially in the introductions of the different chapters.

[3] We call this procedure "nested matching" to adhere to the terminology in this stream of literature. Nevertheless, the procedure only identifies the most-preferred rounds and does not match players and rounds directly.

CHAPTER 2

Matching Strategies of Heterogeneous Agents under Incomplete Information in a University Clearinghouse

Britta Hoyer and Nadja Stroh-Maraun

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CHAPTER 3

Stability in Weighted College Admissions Problems

Britta Hoyer and Nadja Stroh-Maraun

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CHAPTER 4

Pareto Efficiency in Weighted School Choice Problems

Nadja Stroh-Maraun

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CHAPTER 5

Outcome Equivalence in School Choice with Reciprocal Preferences

Claus-Jochen Haake and Nadja Stroh-Maraun

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Haake, C.-J. & Stroh-Maraun, N. (2018). Outcome equivalence in school choice with reciprocal preferences. *Economics Letters*, 170, 39 – 41

CHAPTER 6

A Duration Model Analysis of Consumer Preferences and Determinants of Video Game Consumption

Daniel Kaimann, Nadja Stroh-Maraun and Joe Cox

Terminology:

Note that "matching" or "matchmaking" in this stream of literature refers to the identification of similar skill levels and the forming of preferences on the basis of these skill levels. The allocation of players to existing rounds is not directly considered in this stream of literature as it is assumed that players enter the game sequentially, which makes allocating individual players to the best-fitting round a more straightforward process.

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CHAPTER 7

Variety in the video game industry: An empirical study of the Wundt curve

Daniel Kaimann, Nadja Stroh-Maraun, Joe Cox

Terminology:

Note that “matching” or “matchmaking” in this stream of literature refers to the identification of similar skill levels and the forming of preferences on the basis of these skill levels. The allocation of players to existing rounds is not directly considered in this stream of literature as it is assumed that players enter the game sequentially, which makes allocating individual players to the best-fitting round a more straightforward process.

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CHAPTER 8

More than skills: A novel matching proposal for multiplayer video games

Nadja Stroh-Maraun, Daniel Kaimann, Joe Cox

Terminology:

Note that “matching” or “matchmaking” in this stream of literature refers to the identification of similar skill levels and the forming of preferences on the basis of these skill levels. The allocation of players to existing rounds is not directly considered in this stream of literature as it is assumed that players enter the game sequentially, which makes allocating individual players to the best-fitting round a more straightforward process. We adhere to this terminology by naming our procedure “nested matching”, although it only identifies the most-preferred rounds and does not match players and rounds directly.

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