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University Matching Mechanism in Greece: Evaluation of the Proposed Government Reforms

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Abstract:

Matching mechanisms have been extensively used to address school choice problems worldwide. By setting up a matching model, we analyse the matching mechanism applied in Greek university admission, the Gale-Shapley deferred acceptance algorithm, by describing its desirable properties and its empirical implications. In this context, we evaluate the proposed government reforms on the properties of the mechanism, namely a weighting-factor on student choices and a location-based criterion. We conclude that the weighting-factor would violate strategy-proofness and the matching would be wasteful, whereas the location-based criterion would maintain the algorithm's desirable properties and contribute towards the alleviation of the financial burden of families.

Keywords: University Admission Systems, Matching Mechanisms, Deferred Acceptance Algorithm, Government Reforms

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1. Introduction

The Greek educational system has been a topic of constant debate throughout the decades, with multiple governments attempting to make sweeping changes towards reforming it. Under the current coalition government of SYRIZA and Independent Greeks, a proposed paper to be discussed and voted for in the Greek Parliament was presented in May 2016 that highlighted the administration's attempts towards drastic changes of the secondary and tertiary education system. Amongst the list of proposed reforms include changes in the matching mechanism of university admissions, with the introduction of new criteria designed to provide incentives to students to restrict their number of choices and alleviate the financial burden of the students' families (Ministry of Education, 2016).

Market design and matching mechanisms have become extensively studied in the literature given their importance in school choice problems (Roth 2008, Abdulkadiroglu and Sonmez, 2003, Gale and Shapley, 1962). Several studies have focused on the allocation of students in secondary education and on the desirable properties of matching mechanisms in achieving stable and efficient assignments. Matching mechanisms for university admission have also been considerably analysed, with emphasis being placed on the desirable properties of matching mechanisms, namely stability, Pareto efficiency and strategy proofness (Biro 2008, Ma et al. 2014).

In the current context of tertiary education in Greece, recent statistics have raised concerns about the effectiveness of the system. With an increasing proportion of students studying degrees for which they have little interest, with graduation rates dropping, and with the private cost borne by students' families increasing, the need for a comprehensive re-structuring and reform has been imperative (Ministry of Education, 2016).

This paper examines the proposed Greek tertiary education reforms, by analysing how the reforms would affect the properties of the matching mechanism in university admissions. Specifically, this paper addresses how the proposed weighting factor on student choices incentivizing students to restrict the number of submitted choices and a location-based criterion, that would give priority to students studying close to the universities they applied, would affect the properties of the matching mechanism. As far as the author is aware, this paper is the first to analyse the matching mechanism in the Greek tertiary education system, and the first to assess the effect of the proposed government reforms on matching and its consequences on the allocation outcomes of students to universities. Finally, the paper adds to the existing literature by providing further insights to matching mechanisms applied to university admissions.

To address the research question, we first discuss, in section 2, the theoretical background of matching models, analyse the properties and operation of matching mechanisms and present a brief literature review. In Section 3, we provide a brief description of the Greek tertiary education system. In Section 4, we present the matching mechanism in university admission in Greece. To highlight the empirical consequences of the matching mechanism, Section 5 presents the empirical implications of the mechanism using admission statistics from 2011. Section 6 addresses the research question, namely how the recommended reforms, which include a weighting factor on students' choices and a location-based criterion, affect the properties of the algorithm. Finally, Section 7 discusses and provides policy recommendations, with Section 8 concluding.

2. Theoretical Background & Literature Review

Allocating students to schools has been one of the most prominent topics of market design in recent decades as economists began to identify necessary changes in market design that would improve outcomes (Roth 2002). Roth (2008) argued that the recent focus in matching has been due to the opportunity to correct market failures through devising of rules for centralized and decentralized market organizations. They highlight three aspects of efficient matching that markets are required to possess:

- Thickness, requiring a large number of buyers and sellers to interact in a market (in the case of university selection, it requires many students and universities participating in the market).
- Overcoming congestion, which requires providing enough time for the participants and ensuring that transactions are conducted fast enough.
- Making it safe for the participants in the market to reveal on their information and preferences.

The recent report of the Education Policy Development Centre of the Greek Confederation of Workers (2015) published detailed statistics of the thickness of tertiary education: in 2013, 104,988 students were registered for entry in tertiary education for 446 different university departments in Greece[1]. Additionally, the Greek system can overcome congestion allowing students significant time to consider their choices of universities while the matching is conducted through a centrally managed computerized system under the auspices of the Ministry of Education[2]. In terms of the third aspect, even though the theoretical matching model implemented prevents strategic behaviour, in

[1] Source: Center of Education Policy Development of General Confederation of Greek Workers. "The basic dimensions of education: the Greek primary and secondary education" (2015).

[2] On average, students are given around a month's time to submit a computerized application after receiving their final exam grade in July, with final allocation decisions being made within two-three weeks after the application submission deadline.

practice, many private companies and institutions are operating offering strategic advice on university applications, which might raise some concerns

Before presenting the different matching mechanisms, their properties and applications in the literature, we formulate the one-sided matching model of university admission.

2.1. Formulation of the Matching Model

In a school choice problem, there are a number of students each of whom should be assigned a seat at one of a number of schools (Abdulkadiroglu and Sonmez, 2003). Each student has strict, well-defined preferences over all available schools and herself, and each school has a strict priority ordering over all students, which are determined by applying fixed legal criteria (e.g. the priority ordering determined by the attained final exam grades). In this paper, we consider the case of university admissions, therefore we study the university choice problem.

The university choice problem consists of the following:

1. A set of students $I = \{i_1, \dots, i_n\}$,
2. A set of universities $S = \{s_1, \dots, s_m\}$,
3. A university capacity vector $q = \{q_{s_1}, \dots, q_{s_m}\}$
4. A list of strict student preferences $R_I = \{R_{i_1}, \dots, R_{i_n}\}$,
5. A profile of student preferences is denoted by $R \equiv (R_i)_{i \in n}$,
6. A list of strict university priorities $f = \{f_{s_1}, \dots, f_{s_m}\}$

Firstly, for student i, $s_1\, R_i\, s_2$ means that the student strictly prefers university s_1 to university s_2. Furthermore, it is assumed that $s_m\, R_i\, i$, meaning that student i strictly prefers being assigned a university than being matched with herself, which is the case of non-assignment (change this). Secondly, q_s indicates the capacity of university s, with $\sum_{s \in S} q_s < n$, such that the total available university capacity is smaller than the number of students applying for university: a sub-set of students will be unallocated to universities. Finally, f_s indicates the strict university priority ordering over all students, determined by fixed state criteria.

A matching $\mu : I \rightarrow S \cup I$ is a function from the set I of students to the set $S \cup I$ of universities and students, as if a student is unassigned, she is matched with herself (Ergin and Sonmez, 2006). For a matching to be considered feasible, none of the university capacities q are violated, meaning that no university seat can be assigned to more than one student. Also let $\mu(i)$ denote the assignment of student i under matching μ. The university choice problem under consideration is a one-sided matching problem, where the subjects, the students, reveal their strict preferences over universities, the objects, which have priority orderings determined externally by state criteria.

Denoting by M the set of all feasible matchings allows us to define a matching mechanism φ. A matching mechanism φ is a mapping $\varphi: R \rightarrow \mathsf{M}$ of student preference profiles R and recommends a feasible matching μ (of the possible set of matchings M).

A matching mechanism φ is evaluated based on the following desirable properties that it should have:

1. **Stability**

The matching μ resulting from the matching mechanism φ is a stable matching if the following conditions are satisfied:

i. *It is individually rational* if, for each student $i \in I$, $\mu(i) \, R_i \, i$ and $\mu(i) \neq i$ meaning that student i is matched to an acceptable university and not-herself, and she strictly prefers her assignment to being matched with herself, i.e. non-assignment.

ii. *It is non-wasteful* if, for some student i, $s\ f_s\ \mu(i)$, implies $|\mu(s)| \geq q_s$ meaning that there should be no matching in which student i prefers university s and the quota of s is not exhausted.

iii. *There are no blocking pairs* if there is no pair (i, s) such that $i\ \ f_s\ j$ for some $j\ \in \mu(s)$ and $s\ \ R_i\ \mu(i)$ meaning that there is no assignment in which a seat is allocated to student j even though university s prefers student i to student j. This property eliminates justifiable envy.

2. Strategy-proofness

A matching mechanism φ is said to be strategy-proof if for each preference profile $\mathrm{R_i} \in \mathrm{R}$, each student $\mathrm{i}\ \in \mathrm{I}$ and for every alternate preference $\mathrm{R'_i} \in \mathrm{R_i}$, it is the case that $\mathrm{\varphi_i(R_i, R_{-i})\ R_i\ \ \varphi_i(R'_i, R_{-i})}$. Strategy-proofness means that it is a dominant strategy for each student to report her true preferences, providing no room for strategic behaviour (Dubins & Freedman, 1981; Roth, 1982). Strategy-proofness does not require the assumption of complete information, as it would be a dominant strategy to tell the truth independent of the knowledge of the preference profiles of other students and the priority orderings of universities.

3. Pareto-efficiency

A matching mechanism φ is said to be Pareto efficient at R, if there is no other matching μ such that, for each student $i\ \in I$, $\mu(i)\ \ R_i\ \varphi_i(R)$ and for some $j\ \in I$, $\mu(j)\ R_j\ \varphi_j(R)$. A matching is Pareto efficient if it efficient for all preference profiles R. Intuitively, a matching mechanism φ is said to be Pareto efficient if there is no alternative matching that assigns each student to a weakly preferred university and at least one student to a strictly preferred university.

2.2. Different Matching Mechanisms

Three different matching mechanisms have been analysed extensively in the literature, the Boston Mechanism, the Gale Shapley deferred acceptance algorithm and the Top Trading Cycles algorithm. In this section, we consider the process by which each algorithm matches students to universities through a simple example. Consider the following university choice problem:

1. A set of students $I = \{i_1, i_2 , i_3, i_4\}$
2. A set of universities $S = \{s_1, s_2, s_3\}$,
3. A university capacity vector $q = \{q_{s_1}, q_{s_2}, q_{s_3}\} = \{1,1,1\}$,
4. A list of strict student preferences $R_I = \{R_{i_1}, R_{i_2}, R_{i_3}, R_{i_4}\}$,
5. A profile of student preferences is denoted by $R \equiv (R_i)_{i \in n}$,
6. A list of strict university priorities $f = \{f_{s_1}, f_{s_2}, f_{s_3}\}$.

Since $\sum_{s \in S} q_s < n$, the capacity of universities is smaller than the number of students submitting their preferences; thus, one student will be unassigned in the final matching. The reason we are assuming one student is excluded from university admission is because in the Greek tertiary education system, the number of available spots at universities is lower than the number of students applying each year. Assume that the strict preference profiles of students and the priority orderings of universities are given by the following:

R_{i_1}	R_{i_2}	R_{i_3}	R_{i_4}
s_1	s_2	s_1	s_2
s_2	s_3	s_3	s_3
s_3	s_1	s_2	s_1

f_{s_1}	f_{s_2}	f_{s_3}
i_1	i_1	i_1
i_2	i_2	i_2
i_3	i_3	i_3
i_4	i_4	i_4

Each student's strict preference profile over all universities is given by R_i, so, for example, for student i_1, $s_1\ R_{i_1}\ s_2\ R_{i_1}\ s_3$. The priority ordering of each university is fixed and determined exogenously: we assume that universities prioritize the students according to their attained final examination grades, so student i_1 attained the highest grade, followed by i_2, then by i_3 and finally by i_4.

Finally, let $\varphi^K(R)$ denote the matching chosen by a matching algorithm for the problem R, where K = B refers to the Boston Mechanism, K = G refers to the Gale-Shapley algorithm and K = T to the Top Trading Cycles algorithm. In all cases, each student $i \in I$ submits a preference ranking $Q_i \in R_i$, with all rankings submitted simultaneously. Consequently, given the profile of reported preferences $Q \in R$, the mechanism φ determines a matching $\varphi^K(Q)$.

We now turn our analysis towards how each matching mechanism allocates students i_1 to i_4 to universities s_1 to s_3.

2.2.1. Boston Mechanism

The first matching mechanism extensively studied in the literature is the Boston Mechanism. The algorithm works as follows (Abdulkadiroglu and Sonmez 2003)

Step 1: Only the first choices of students are considered. For each university, it considers the students who have listed it as their top choice and assigns seats to these students one at a time following their priority order f_s until either there are no seats left or no student left who has listed it as her first choice.

In general, at:

Step k: Consider the remaining students, where in round k only the kth choices of students are considered. For each university that has available seats, consider the students who have listed it as their kth choice and assign the remaining seats to these students one at a time following their priority order f_s until there is no student left who has listed it as her kth choice.

Following the example presented above:

Step 1: Only the first choices of students are considered. Student i_1 is assigned to university s_1, student i_2 to university s_2, with students i_3 and i_4 being unassigned in step 1 as the capacities q_{s_1} and q_{s_2} are exhausted.

Step 2: Only the second choices of students are considered. Student i_3 is assigned to university s_3, with student i_4 being excluded from the final allocation as there are no remaining seats available.

The final matching under the Boston Mechanism is the following:

$$\varphi^B(R) = \begin{pmatrix} i_1 & i_2 & i_3 & i_4 \\ s_1 & s_2 & s_3 & - \end{pmatrix}$$

Student i_1 is allocated to university s_1, i_2 to university s_2, i_3 to university s_3, with student i_4 being unallocated.

Roth (1982) showed that the outcome of the Boston Mechanism is not strategy-proof, as a student may lose priority at a school unless she ranks it as his first choice, providing room for strategic play: for example, student i_4 would be strictly better off concealing her true preferences, selecting s_3 as her top choice, in which case she would be allocated a spot at s_3, which she strictly prefers to non-allocation. Abdulkadiroglu and Sonmez (2003) also argued that if students submit their true preferences, then the matching induced by the Boston mechanism is Pareto-efficient; however, given that the mechanism is subject to manipulability by the subjects, as presented above, the final matching is unlikely to be Pareto efficient.

In an experimental study, Chen and Sonmez (2006) showed that under the Boston mechanism, even though more than 70% of students were assigned a seat at the school of their first choice, given that 80% of them misrepresented their true preferences, less than 30% of the students were actually assigned a seat at their most-preferred school based on their true preferences, a finding consistent with the violation of strategy-proofness of the Boston mechanism.

2.2.2. Gale-Shapley Deferred Acceptance Algorithm

The second matching mechanism under consideration and the one employed in Greece for university admissions, is the Gale-Shapley algorithm, also referred to as the deferred acceptance algorithm, abbreviated as DA algorithm and will be referred as such further on. The algorithm works as follows (Gale and Shapley, 1962):

Step 1: Each student applies to her first-choice university. Each university tentatively assigns its seats one at a time following their priority order until there are no seats left, and rejects the remaining applicants.

In general, at

Step k: Each student who was rejected in the previous k-1 steps applies to her kth choice university. Every university considers the students it has been holding from the previous steps along with new applicants and tentatively assigns its seats one at a time following their priority order until there are no seats left, and rejects the remaining applicants.

The algorithm terminates when there is no student rejected or there are no further available seats and all rejected students have exhausted their preference lists.

Following the example presented above:

Step 1: Each student applies to her first-choice university. University s_1 tentatively assigns its seat to student i_1 and rejects i_3, university s_2 assigns its seat to student i_2 and rejects i_4.

Step 2: Each student, who was rejected in Step 1, applies to her second-choice university. Students i_3 and i_4, who were rejected in Step 1, apply to their second-choice university, namely s_3. Universities s_1 and s_2 do not change their assignments as no new students have applied in Step 2, with university s_3 assigning its seat to student i_3 and rejecting i_4.

In the example above, the algorithm terminates at Step 2, as student i_4 has been rejected from all his choices. The final matching under the DA algorithm is the following:

$$\varphi^G(R) = \begin{pmatrix} i_1 & i_2 & i_3 & i_4 \\ s_1 & s_2 & s_3 & - \end{pmatrix}$$

The matching produced from this mechanism is stable (Gale and Shapley, 1962). Furthermore, the mechanism is strategy-proof as truth-telling is a dominant strategy for students. Students do not risk losing their priority if they do not rank the university high in their preferences, allowing students to consider admissions independent of preference ranking, thus enabling them to truthfully reveal their preferences (Roth 1982, Dubins and Freedman 1981). However, the algorithm violates Pareto-efficiency highlighting that there is a trade-off between Pareto-efficiency and stability: there might be another matching which is preferred by each student to the current final matching, i.e. it is not Pareto efficient. (Abdulkadiroglu and Sonmez, 2003).

In the case of uniform priorities of universities, the DA algorithm is akin to serial dictatorship, meaning that the first student is assigned a seat at her first-choice university, the next student is assigned a seat at her top-choice university among the remaining ones, etc.

The literature has highlighted the Gale-Shapley algorithm as the one of choice, in terms of the desirability of its properties and Pareto-dominating any other mechanism that eliminates justified envy. Biro (2008) analysed the effectiveness of the DA algorithm on university admission in Hungary, the system of which has the unique characteristic of "score-limits", showing that the algorithm led to a stable and efficient matching. Additionally, Abdulkadiroglu and Sonmez (2003) and Ergin and Sonmez (2006) have emphasised the importance of the DA algorithm, leading to significant changes and reforms in school matching systems across the United States.

2.2.3. Top Trading Cycles Algorithm

The final matching mechanism that has been studied is the Top Trading Cycles Mechanism (Abdulkadiroglu and Sonmez 2003). The algorithm works in the following way:

Step 1: Each student points to her first-choice university under her revealed preferences. Each university points to the student who has the highest priority for the university. Every student in a cycle is assigned a seat and is removed.

In general, at

Step k: Each remaining student points to her favourite university among the remaining ones and each remaining university points to the student with the highest priority among the remaining students. There is at least one cycle and every student in a cycle is assigned a seat and is removed.

The algorithm terminates when all students are assigned a seat or when there are no further available seats.

Following the example presented above:

Step 1: Student i_1 points to university s_1, university s_1 points to i_1, i_2 points to s_2, university s_2 points to i_1 (similarly for universities s_3 and s_4), so the assignment after the first cycle is (s_1, i_1), as only one seat at university s_1 can be assigned.

Step 2: Student i_2 points to university s_2, university s_2 points to i_2, i_3 points to university s_3, and university s_3 points to i_2, so the assignment after the second cycle is (s_2, i_2).

Step 3: Student i_3 points to university s_3, university s_3 points to i_3, so the assignment after the third cycle is (s_3, i_3).

The algorithm terminates at Step 3 as there are no further available seats. The final matching is the following:

$$\varphi^T(R) = \begin{pmatrix} \mathrm{i}_1 & \mathrm{i}_2 & \mathrm{i}_3 & \mathrm{i}_4 \\ \mathrm{s}_1 & \mathrm{s}_2 & \mathrm{s}_3 & - \end{pmatrix}$$

In the case where all universities have the same priority ordering, the algorithm is akin to a serial dictatorship as in the case of the DA algorithm. The Top Trading Cycles algorithm is strategy-proof, since a student removed at Step k has achieved a grade that would not allow her to be removed earlier, thus misrepresenting her preferences would not alter the final assignment; consequently, truthful revelation of preferences is a dominant strategy. Furthermore, it is also Pareto efficient, unlike the DA algorithm, since any student removed at Step k is assigned her top available choice and thus cannot be made better off (Abdulkadiroglu and Sonmez 2003).

In an experimental study exploiting a change in the matching mechanism in China, and using reported student preferences and matching outcomes during college admission, Ma et al. (2014) found that the change from the Boston Mechanism to the Top Trading Cycles mechanism reduced gender differences in college admissions but failed to improve the fairness and strategic decision-making by students.

A problem common amongst matching mechanisms highlighted in the literature is the case of a quota placed on school choice: this translates to a truncation of the preference profile R_I of students to a restricted set K_I. Haeringer and Klijn (2009), in their comparison of different admission systems in secondary schools in multiple US states, found that a quota on the number of student choices led to strategizing and thus violation of strategy-proofness. They concluded that, given a specific quota, any Nash equilibrium is also a Nash equilibrium under a less stringent quota, arguing for the relaxation of quotas and for allowing students to have an unrestricted preference ordering. Furthermore, Calsamiglia et al. (2011) showed that restricting the number of schools had a large negative effect on the manipulability of the matching mechanisms, with truth-telling no longer being a dominant strategy leading students to strategize in their decision-making: they argued for the removing of choice constraints to improve the performance of the school choice mechanisms.

3. The Greek Tertiary Education System

This section provides a brief overview of the Greek tertiary education system. Specifically, we present the structure, university application and grading process for high-school students, which will facilitate the understanding of the matching mechanism and its application to university admissions in Greece.

3.1. Structure of Tertiary Education

The tertiary education in Greece is public, free of charge and centrally funded by the Greek government. It is comprised of Higher Education Institutions (AEI)[3] and Technical Education Institutions (TEI)[4]. The number of departments in tertiary education has remained at a very high number, with 405 departments being available for student selection in 2016, including a significant number of small departments and degree programs that enrolled a very small number of students (Hellenic National Examination Body, 2016).

The process of national examinations and entrance of students in AEI and TEI's is centrally controlled by the Ministry of Education, with university departments or local governments not having decision-making power, but being able to negotiate the quotas of each department and the level of funding. The number of students admitted to each university department per year complies with the principle of "numerus clausus" and is fixed by the Ministry of Education, with each department solely providing suggestions for the number of students (Eurydice, 2009). Thus, the matching problem in Greece is a one-sided problem, where universities are indivisible objects which are assigned to students based on student preferences and university priorities.

[3] Includes Universities, Polytechnics and the Higher School of Fine Arts.

[4] Includes Higher Technological Institutes and the Higher School of Pedagogical and Technological Education.

3.2. Selection of Subjects in High School

During the final two years of high school, referred as "Eniaio Lykeio", students can choose one of three option streams, referred to as "directions", depending on their intended course of study at university (Ministry of Education, 2016): the options include the Humanities, Sciences and Economics & IT. Depending on the direction, students are required to take different core subjects, 4 per direction. For example, if a student follows the Humanities direction, she would study Ancient Greek, History, Latin and Literature, the grades of which would determine her entry grade into tertiary education. To receive the high-school diploma or "Apolytirion", students are also required to follow 9 General Education subjects which are assessed orally and written-based, which do not, however, form part of their final entry grade to tertiary education.

3.3. Application to University and Grading Scheme

Once students complete the National Examinations usually held in May of every year, they are expected to wait a period of 2 months until their national exam grade is issued around the month of July. The national exam grade is calculated by considering the written exam grades of the 4 national exam subjects that students have followed in the last two years of high school. Each written exam is graded out of 20, with 10 being the passing grade. The calculation of the final grade depends on the choice of studies of the student: for example, if the student has chosen a degree in the humanities/legal/social sciences, the subjects with the highest weight would be Ancient Greek and History, whereas if she has chosen a degree in Life Sciences, the highest-weight subjects would include Biology and Literature with different weights. In terms of the matching mechanism, this characteristic of the Greek system translates into a non-uniform priority ordering of universities over the set of students: the priority ordering f_s depends on the course of study selected by each student.

The final grade is scaled differently such that the maximum a student can attain (without consideration of special degrees such as architecture, which require further examinations) is 20,000 points or "moria" as will be referred further on. An example of how the final grade is calculated is the following:

Assume a student follows the Humanities Direction, and wishes to study Law at the University of Athens. The subjects, grades and final entrance grade are presented below. **Ancient Greek has an added weight of 1.3 and History an added weight of 0.7**.

	Ancient Greek (core)	**History (core)**	Literature (core)	Latin (core)
Final Grade	18.9	19.1	17.3	18.5

National Entry Grade (scaled) = [(18.9 + 19.1 + 17.3 + 18.5) * 2 + (18.9 * 1.3) + (19.1 * 0.7)] * 100 = **18,554 out of 20,000 "moria"**

Table 1: Calculating the Final Entry Grade

Once the grades have been finalized around July, students submit a computerized application where they declare their preferences for university departments they want to be admitted, which effectively increase the number of available choices. Students have an unlimited number of choices in their selection process, as there is no quota applied. Applying to university departments instead of universities is translated in the matching model as an increase in the number of universities in set S, from which the students submit their complete preference profile R.

4. The Matching Mechanism in Greece

In Greece, matching for university admissions is managed centrally, under the auspices and supervision of the Ministry of Education. The university choice problem in Greece is a one-sided problem, as mentioned previously, where the subjects, the high-school students, reveal their strict preferences over universities, the objects, which have priority orderings determined externally by state criteria. The priority ordering is non-uniform and depends on the course of study and subject selection of each student, and it is in descending order of attained student grades.

Even though the ordering of students is based on the final written grade on the national exam, the Greek law specifies certain categories of students with priority entry, irrespective of their performance in the final exam: for example, students with health problems, from low-income backgrounds or families with several children, receive priority in admission. However, this paper examines the general case of student ordering based on the graded performance in the national exam, and the effect of the recommended reforms on the properties of the matching mechanism. In terms of a tie-break between two or more students achieving the same national exam grade, the student with the highest grade in the subjects with the greater weight in the field of study she is applying to (e.g. History and Ancient Greek in our example above) is admitted to university. If there is still a tie-break, both students are admitted to the department for which they were tied in, meaning that, in principle, the capacity of universities would increase to accommodate the students.

The matching mechanism applied by the Greek government is the DA algorithm. As in the example formulated in Section 3, with the same student preferences and university priority orderings, the final matching is:

$$\varphi^G(R) = \begin{pmatrix} i_1 & i_2 & i_3 & i_4 \\ s_1 & s_2 & s_3 & - \end{pmatrix}$$

As highlighted in Section 2, the matching mechanism is stable and strategy-proof, however not Pareto-efficient. In the DA algorithm where the number of students applying for admission exceed the available capacity, the worst-performing students, which in this case includes student $\mathbf{i}_4$, are not allocated a spot. This is a desirable outcome, given that it allows students with the highest-attained grades to study at university. However, it might also be considered an unfair outcome, if student admission is solely determined by a single national exam, without further secondary exams/evaluation from each university they are applying to; yet, this is not a drawback of the matching mechanism per se, but rather follows from the fact that the uniform priority orderings of universities are determined solely by attained exam grades. The serial dictatorship mechanism, the special case of the DA algorithm with uniform university priority orderings, satisfies the best-available choices of the highest-graded students, thus students who might not perform well on the national exam might be greatly disadvantaged in the matching mechanism.

Having examined the matching mechanism applied in university admissions in Greece, the next section presents the empirical implications of the matching mechanism and how they are linked with the algorithm.

5. Empirical Implications of the Matching Mechanism in Greece

In the published May 2016 Findings titled "National and Social Dialogue on Education", the government committee responsible for proposing changes to the Greek education system, filed their policy proposals to the parliament. In one section, the findings focused on the admission process of students from secondary to tertiary education, with two key quotes that highlighted the reasoning behind the reforms worth pointing out (translated from Greek):

"How, if not destructive, can this system be characterized, when 8 out of 10 students do not study what they are interested in?[5]*"*

"Every year, a domino effect is created in the form of an avalanche from the rejected students in the high-scoring universities sliding down to the lower-scoring universities, driving away those students that had selected them as their first choice."

To understand the reasons behind the empirical observations, we recap the matching model of Section 3 adapted with the specific Greek characteristics:

1. A set of students $I = \{i_1, \dots, i_n\}$, where n is relatively large compared to the number of available seats in universities which are preferred by students (preferred refers to a university being included in the top 5 choices of a student application).
2. A set of universities $S = \{s_1, \dots, s_m\}$, where m is also relatively large, and contains a large number of universities which are geographically isolated and have very small departments with low quality of teaching (and are included as safety or least-preferred choices by students).

[5] The "interested-in" refers to students being accepted to university departments within their Top 5 choices in their university applications.

3. A university capacity vector $q = \{q_{s_1}, \dots, q_{s_m}\}$, where the capacity of high-quality universities is limited compared to their demand.
4. A list of strict student preferences $R_I = \{R_{i_1}, \dots, R_{i_n}\}$ over all available university departments, with the mean number of choices in a university application being equal to 28.4 in 2011[6].

Table 2 complements the above by illustrating the student choices drawn from the computerized application for 2011, categorized in different university groups. We select year 2011 as it is the latest available year for which analytical statistics on student choices and preferences were publicly available. Each group is differentiated according to its degree of competitiveness and attractiveness. The degree of competitiveness is defined as the ratio $\frac{\text{number of successful applicants}}{\text{total number of applicants}}$, with a lower ratio indicating a higher level of competitiveness. Attractiveness is defined as the ratio $\frac{\text{applicant choices in their Top 3 Choices}}{\text{total number of applicant choices}}$ in each department with a higher ratio indicating a higher degree of attractiveness. The 1st Group contains departments which are the most competitive and attractive, whereas the 4th Group contains departments with low competitiveness and low attractiveness.

The first observation drawn from Table 2 is that only 18.4% of departments of tertiary education were characterized as highly competitive and attractive, with their total available capacity equalling 11,140 spots in 2011 (Ministry of Education, 2011). 57.4% of departments were, however, characterized by low competitiveness and attractiveness, with their total available capacity equal to 31,228 spots in 2011.

[6] Source: Ministry of Education – Annual Press Releases of Entry Results (2011)

	Group Identification (2011)
1st Group	18.4% of departments of tertiary education, characterized by departments with high competitiveness and high attractiveness
2nd Group	9.0% of departments of tertiary education, characterized by departments with low competitiveness and high attractiveness
3rd Group	15.2% of departments of tertiary education, characterized by departments with high competitiveness and low attractiveness
4th Group	57.4% of departments of tertiary education, characterized by departments with low competitiveness and low attractiveness

	Groups			
	1st Group	2nd Group	3rd Group	4th Group
% of 1st choice	10.5%	6.5%	2.6%	1.5%
% top 3 choices	27.4%	19.3%	8.4%	6.1%
% above 3rd choice	72.6%	80.7%	91.6%	93.9%

Table 2: Applicant Choices by different university department groups[7]

The second observation drawn is that moving from the 1st to the 4th Group, the % of first choice as well as the % of Top 3 choices drops steadily, meaning that the lower the department is ranked in terms of competitiveness and

[7] Source: Ministry of Education – Annual Press Releases of Entry Results (2011)

attractiveness, the least likely students are in selecting it in their first three choices. Furthermore, the % above 3rd choice increases from 72.6% in the 1st Group to 93.9% in the 4th Group, indicating that students select university departments with low competitiveness and low attractiveness in their least preferred choices.

Figure 1 complements Table 2 above by presenting the successful students in different groups as well as the number of students placing the departments in each group as one of their first or top three choices. For example, in the 1st Group, 51.7% of applicants had departments of the 1st Group as their first choice, whereas 79% of applicants had them within their first three choices; out of the total applicants in this group, only 29.9% were successful and 70.1% were unsuccessful. Therefore, the unsuccessful candidates would be "domino-ing" down to the less attractive and competitive groups to be allocated a spot at a university.

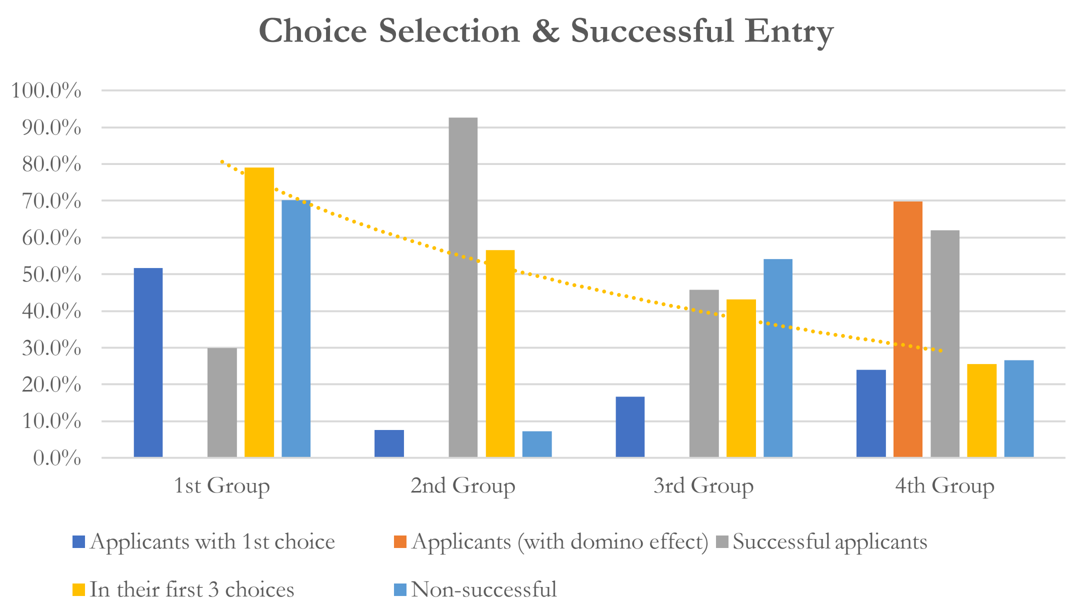

Figure 1[8]

[8] Source: Ministry of Education – Annual Press Release of Entry Results (2011)

There are two important conclusions drawn from Figure 1. Moving from the most competitive and most attractive university departments (1^{st} Group) to the least competitive and least attractive ones (4^{th} Group):

- the percentage of successful candidates increases (except for the 2^{nd} group which had a very small sample size and is also the group that has a low competitiveness with high attractiveness, thus the success percentage is expected to be significantly higher, given that competition for entry was relatively low) from 30% to 61% of total students in that group.
- the % of candidates including the departments within their first three choices decreases significantly from 79.0% in the 1^{st} Group to 25.5% in the 4^{th} Group.

However, both empirical conclusions drawn from Table 2 and Figure 1 are a direct consequence of the application of the DA algorithm under the unique Greek system. Given limited capacity in the most-demanded universities and the unrestricted preference profiles of students, only students with the highest grades and thus at the top of the priority ordering f of universities would be allocated spots at their most-preferred choices. Students, who were rejected in the previous steps of the algorithm, would domino-down and take the spots from lower-grade students who had selected the universities as their top choice. In general, in step k of the algorithm, every university considers the students it has been holding from the previous steps along with new applicants and tentatively assigns its seats one at a time following their priority order until there are no seats left, and rejects the remaining applicants. In fact, any matching mechanism that respects the priority ordering with respect to grades will lead to a domino-down effect; if the matching mechanism is to be also strategy-proof, then the DA algorithm is the preferred one.

Therefore, the domino-effect follows directly from the way the matching mechanism operates. The consequence is that students in the lower priority orderings of the universities would be assigned spots at universities in their least-preferred choices. However, given that $s_m \, R_i \, i$, meaning that student i strictly prefers being assigned a university than being matched with herself, which is the case of non-assignment, a student who is assigned a spot at a university outside her top choices is strictly better-off than non-assignment, thus the matching mechanism does produce a stable allocation and individual rationality is satisfied.

However, even though the matching mechanism is stable and strategy-proof, the government is attributing the empirical observations to the mechanism itself and has proposed two reforms that are analysed in the following section.

6. Proposed Reforms and their Effect on Matching

The proposed reforms, as outlined in the Ministry of Education's 2016 Findings Paper, include sweeping changes to primary, secondary and tertiary education in Greece. Among the reforms on the tertiary education sector that would affect the matching mechanism, and which are analysed next, include the introduction of a weighting factor on the number of student choices and a location-based criterion that would prioritize students living closer to universities they are applying for.

6.1. Weighting Factor on Number of Choices: Effect on Matching

The first reform is a weighting factor that rewards students that restrict their number of choices to less than 10 university departments. To justify the reform, the Ministry of Education argued that the unconstrained choice set of students eventually led to them being allocated to universities for which they had little interest in attending.

The following table illustrates the proposed reform, drawn directly from the official report:

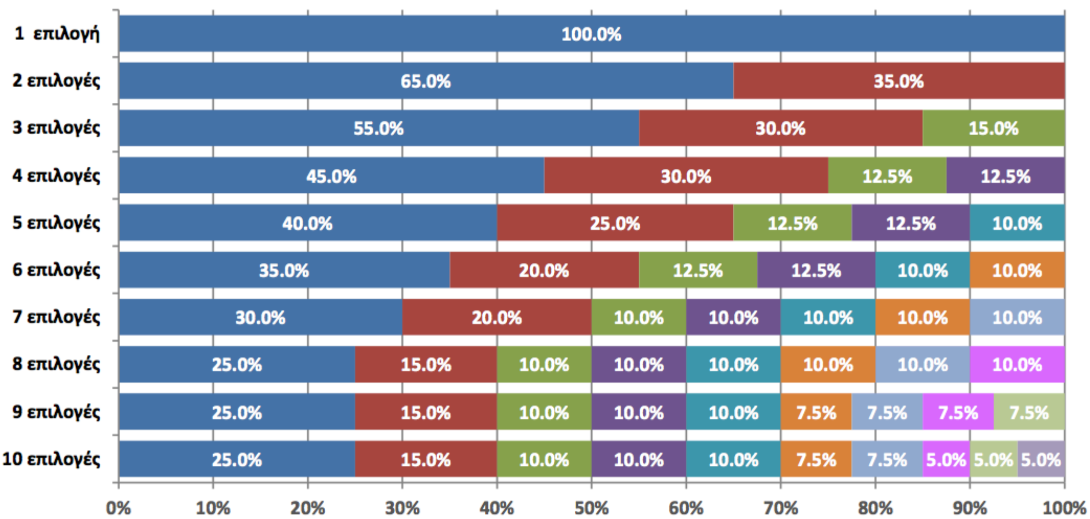

Table 3: Range of weighting factors according to the number of choices of an applicant[9]

[9] Source: Ministry of Education – Annual Press Releases of Entry Results (2011)

The Y-axis contains the number of choices submitted by a student i, from one choice at the top to 10 choices at the bottom of the axis. The X-axis contains the different percentages of the weighting factor applied to each student choice. To comprehend Table 3, assume a student restricted her preference ordering to a single university department, and she followed the Humanities Direction scoring 18,554 out of 20,000 in the matriculation exam (as per the example from Table 1). To reward the student for restricting her choice to her most-preferred department, her entrance grade would be increased by 100% of a fixed number of "moria" determined by the "smallest value of the range between the general entrance grade of the first and last successful entrant of the 404 university departments of tertiary education in 2011"[10]. For example, if the minimum range between the highest and lowest-grade successful students in a university department was 400 "moria", then the student's entrance grade to tertiary education would be increased from 18,554 to 18,994, an increase of 2.4%. Consequently, the probability of being accepted to the department of her choice would be significantly increased.

As Table 3 illustrates, the weighting factor decreases steadily from the 1st until the 10th choice: for example, if a student has selected three universities in her application, then her entrance grade to her 1st choice department would be increased by 55% of 400 moria, her 2nd choice by 30% of 400 moria and finally her 3rd choice by 15%. Effectively, the list of strict university priorities $f = \{f_{s_1}, \dots, f_{s_m}\}$ would not be uniform and would change depending on the number of preferences declared by student i.

[10] The fixed value would be calculated each year according to the formula stated above: in the case stated in the reform, the value is calculated for the year 2011. (Source: Ministry of Education – Annual Press Releases of Entry Results (2011))

To understand how the weighting factor would affect the matching mechanism, consider the example used in Section 4 with an additional assumption. Since students decide their choice of universities after the announcement of their final examination grade, they would be more likely to include choices that they have a chance of satisfying: for example, it is a reasonable assumption to make that a student with 18,554 moria would not choose a university that, during their last admission cycle in the previous year, accepted students that had 19,000 and above moria[11]. Therefore, to evaluate the effect of the reform, we focus on a sub-set of students $K \in I$ who achieve grades relatively clustered to each other, and thus, restricting the number of choices would change their relative position in the priority ordering of universities. In other words, the range of grades of students i_1 to i_4, in our example, is relatively small such that a restricted preference profile influences the priority ordering of universities (student i_4 would be preferred to student i_3 if student i_4 restricts her preferences to m-1 universities). Grade clustering is a phenomenon commonly observed in the Greek National Examinations, especially in years where examinations are easier (Charalambopoulou, 2016).

As before, the revealed preferences of students and the priority ordering of the universities are given by the following:

R_{i_1}	R_{i_2}	R_{i_3}	R_{i_4}
s_1	s_2	s_1	s_2
s_2	s_3	s_3	s_3
s_3	s_1	s_2	s_1

[11] This is referred to as the "base" of each university department: a base of 19,000 moria means that the student who has accepted last in that department the previous year had scored 19,000 in the national exam. The "base" acts as a reference guide for student applications, since it guides them towards selecting university departments that they will potentially be able to get into.

f_{s_1}	f_{s_2}	f_{s_3}
i_1	i_1	i_1
i_2	i_2	i_2
i_3	i_3	i_3
i_4	i_4	i_4

Before the weighting factor, the final matching is given by:

$$\varphi^G(R) = \begin{pmatrix} i_1 & i_2 & i_3 & i_4 \\ s_1 & s_2 & s_3 & - \end{pmatrix}$$

The matching mechanism would not be strategy-proof: for each preference profile $R_i \in R$, each student $i \in K$ and for every alternate preference list $R_i' \in R_i$, it is no longer holds that $\varphi_i(R_i, R_{-i})\ R_i\ \varphi_i(R_i', R_{-i})$. To illustrate this, assume that student i_4 is the student in the previous example is currently not allocated any spot at a university, even though $s_m\ R_i\ i$ meaning she strictly prefers being assigned than being matched to herself. Therefore, she would be strictly better-off restricting her preference set from R_{i_4} to R_{i_4}', declaring m-1 preferences over universities, which, given the assumption of grade clustering, would lead student i_4 being ranked higher in the priority ordering of universities than student i_3. Thus $\varphi_i\left(R_{i_4}', R_{-i}\right)\ R_i\ \varphi_i\left(\ R_{i_4}, R_{-i}\right)$, meaning strategy-proofness would be violated.

Consequently, student i_3 could be better-off by concealing her true preferences as truth telling would be a dominated strategy, restricting her preferences to m-1 universities, increasing her final grade and thus being able to be allocated to a university. Students would eventually restrict their preference orderings to one choice, with the final restricted preference ordering of students being the following:

R_{i_1}	R_{i_2}	R_{i_3}	R_{i_4}
s_1	s_2	s_1	s_2

The matching mechanism, in this case, is still well-defined, and would produce a feasible matching. The final matching, given the restricted revealed preferences of students above, is given by:

$$\varphi^G(R) = \begin{pmatrix} i_1 & i_2 & i_3 & i_4 \\ s_1 & s_2 & - & - \end{pmatrix}$$

In the final assignment, two students, i_3 and i_4, are left unallocated, due to declaring only one preference, which due to limited capacities of universities s_1 and s_2, could not be satisfied. The matching mechanism is not strategy-proof as the students not-allocated are strictly better-off concealing their true preferences by including university s_3 as their top choice, thus being allocated a spot at s_3, which they strictly prefer to non-allocation.

Furthermore, the matching mechanism is wasteful given that, for example, for student i_3, $s_3 \; f_{s_3} \; \mu(i_3)$, however $|\mu(s_3)| < q_{s_3}$: even though student i_3 would prefer university s_3 than non-allocation, the capacity q_{s_3} is not exhausted. A similar argument can be made for student i_4, indicating that the matching mechanism induced by the proposed reform would be wasteful and would therefore lead to a non-stable final matching. If implemented, a likely matching would contain a significant number of assignments where students are matched with themselves, and therefore excluded from university.

It is likely that such a reform would be very difficult to implement, as the criteria are unclear and ambiguous, and would, therefore be very challenging to explain effectively to students and their families. The reform would, additionally, violate the desired properties of the DA algorithm, namely stability and strategy-proofness.

A potential practical negative consequence of the reform in Greece would be students significantly reducing their choice set to benefit from the grade incentive, while strategizing and concealing their true preferences. Even though knowing the true preferences of students is very difficult in practice, it is reasonable to assume that "smart" students would strategize at the expense of others who are less "smart" to take advantage of the grade incentive and receive priority for the universities of their choice. Other factors which might strengthen decision-making include the popularity of top choices of applicants, the priorities at different universities and the degree of risk aversion of students (Abdulkadiroğlu et al., 2006). Furthermore, given the complicated nature of the reform, confusion amongst students and their families could ensue in their attempts to maximize the probability of entering their preferred university, which might compromise their decision-making and eventually their admission to university.

A similar conclusion has also been reached in the literature, although studying constrained choice sets. For example, Haeringer and Klijn (2010), studying a constrained school choice problem in the US, found that constraining the students' choices is a very costly policy which forces them to strategize, thus the property of strategy-proofness is violated, as in our example above. Furthermore, Calsamiglia et al. (2011) confirmed that strategizing follows from constraining choice sets, as they showed that introducing choice constraints in school choice led to truth-telling becoming a dominated strategy, and proposed an unconstrained choice set as a solution towards restoring the desirable properties of the matching mechanism.

6.2. Location-based Criterion: Effect on Matching

The second recommended reform by the Ministry of Education includes the addition of a location-based criterion for the matching mechanism for tertiary education. This would give students priority above and beyond their national examination grades if they applied to a university near their home location. The reform has not yet provided further details on how the location-based criteria would be introduced: it could, potentially, be a scaling factor that is applied to the choices of candidates close to their home, effectively increasing their grade by a certain percentage. The priority orderings of universities would, therefore, be non-uniform, and would depend both on the course of studies of students and their area of residence.

The proposed reform comes as an increasingly greater percentage of families are struggling to support their children to study at a university outside their home. In a comprehensive study, Psacharopoulos and Papakonstantinou (2005) used a sample of 3,000 first year university entrants in Greece to show that in a free-for-all higher education country, the private cost families have to bear (including tuition expenses for preparation for entrance examinations and living expenses of their children among others) exceeded the public (state) spending on tertiary education; not surprisingly, they also found that poorer households spend a much higher percentage of their income on their children's education compared to other income groups.

To analyse the effect of the suggested reform on the properties of the matching mechanism, consider the example used in this paper with the following additional assumption: universities s_1, s_2 and s_3 are engineering schools and students i_1 to i_4 are applying for the same course of study (refer to Section 3). Therefore, before the introduction of the location-based criterion, the priority orderings of the universities are uniform and determined by student grades. Additionally, we focus on a sub-set of students $K \in I$ who achieve grades relatively clustered to each other as before, such that the location-based criterion would change the priority orderings of the universities; in other words, the range of grades of students i_1 to i_4 is sufficiently small[12]. The revealed preferences of students and the priority ordering of the universities are given by the following:

R_{i_1}	R_{i_2}	R_{i_3}	R_{i_4}
s_1	s_2	s_1	s_2
s_2	s_3	s_3	s_3
s_3	s_1	s_2	s_1

f_{s_1}	f_{s_2}	f_{s_3}
i_1	i_1	i_1
i_2	i_2	i_2
i_3	i_3	i_3
i_4	i_4	i_4

Before the location-based criterion, the final matching is given by:

$$\varphi^G(R) = \begin{pmatrix} i_1 & i_2 & i_3 & i_4 \\ s_1 & s_2 & s_3 & - \end{pmatrix}$$

Now, assume, that the engineering university s_3 is close to the proximity of student i_4, and thus university s_3 would prefer student i_4 than i_3. Thus, the new priority ordering of universities is the following:

f_{s_1}	f_{s_2}	f_{s_3}
i_1	i_1	i_1
i_2	i_2	i_2
i_3	i_3	i_4
i_4	i_4	i_3

[12] For example, we do not consider cases where students i_1 to i_3 have achieved relatively high grades (e.g. 19,000 moria) and student i_4, who is resident close to a university *s*, a relatively low grade (e.g. 15,000 moria) since the location-based criterion would not apply. University *s* would still rank students i_1 to i_3 higher in its priority orderings than student i_4.

Student i_4 is now ranked higher in the priority ordering of university s_3 than student i_3, given that she lives close to s_3. With the consideration of the location-based criterion, the final matching is given by:

$$\varphi^G(R) = \begin{pmatrix} i_1 & i_2 & i_3 & i_4 \\ s_1 & s_2 & - & s_3 \end{pmatrix}$$

Compared to the original matching, student i_4 is now allocated a spot at university s_3, whereas student i_3 is left unallocated. The matching mechanism, with the location-based criterion, also has the desirable properties of the original mechanism, namely the following:

1. **Stability**

With location-based incentives, the matching mechanism is stable. The matching is non-wasteful as the quotas of all universities are fully exhausted, it is individually rational as students are assigned to an acceptable university such that they weakly prefer their assignment to being matched with themselves (i.e. non-assignment), and there are no blocking pairs whereupon there is no assignment in which a seat is allocated to student j even though university s prefers student i to student j.

2. **Strategy-proofness**

Strategy-proofness requires that no student can benefit by unilaterally misrepresenting her preferences, meaning that if satisfied, the truthful revelation of preferences becomes a dominant strategy (Balinski and Sonmez 1999). In this matching mechanism, there is no incentive for any student to misrepresent her preferences, thus truth-telling is a dominant strategy and strategy-proofness is maintained: for example, student i_4's dominant strategy is to reveal her true preferences, since misrepresenting them and including another university s as her top choice would not change her assignment; similarly, for all the other students declaring their preferences.

7. Discussion and Policy Implications

The DA algorithm in university admission in Greece leads to a stable and strategy-proof final matching. The introduction of a location-based criterion would maintain the desirable properties of the algorithm. However, the introduction of a weighting factor to incentivize the restriction of student choices would be highly ineffective since the matching mechanism would be neither stable, as the property of non-wastefulness would be violated, nor strategy-proof, as there would be a strong incentive for students to conceal their true preferences to increase their chances of entering a more-preferred university. Additionally, it could lead to difficulties in its implementation given its complexity and thus cause confusion to families and children alike.

However, the unique characteristics of the Greek system, specifically the large number of small, low quality and unpopular university departments, the relatively large number of students eligible for entry into tertiary education, and the unconstrained choice set lead to a final matching that assigns spots to students in departments which they selected in their least-popular choices. However, this paper argues that reforms should be targeted towards changing the relative student and university department numbers, rather than modifying the matching mechanism, since it would violate its desirable properties. Changing the matching mechanism would not change the undesirability of a significant number of university departments.

The government could, therefore, consider alternative policies to reduce the available choices of students in tertiary education to avoid violating the desirable properties of the matching mechanism. To restrict the submitted preferences in each preference profile $R_i \in R$, the government could:

i. Close a significant number of university departments for which there is low demand and steadily abolish TEI's, which could be merged with higher education institutions (OECD 2011). This would mean that the preference profile $R \equiv (R_i)_{i \in n}$ of each student would be truncated, and specifically the low-end, i.e. least preferred, of the preference profiles.

ii. Introduce secondary entrance exams for university departments, providing the opportunity for university departments to have decision-making power over the students they enrol. This would change the priority orderings f of each university over the set of students, and would alter the matching problem to a two-sided problem where both students and universities are subjects who have preferences over the other.

iii. Restrict/truncate the number of choices to an upper bound (for example up to 10 choices). Despite the potential negative consequence of the violation of strategy-proofness, (Haeringer and Klijn, 2010, Calsamiglia et al., 2011), this measure could lead to a stable matching outcome, and an increased number of students attending universities they are more interested in. Quotas in university applications have been implemented in university admission systems throughout the world.

The government could, therefore, combine the two following reforms: the location-based criterion and the truncation of student choices to an upper bound. The combination of the two reforms would achieve the government's desired outcomes. Firstly, the location-based criterion would be a desirable addition to the priority orderings of universities, as it would prioritize students living closer to their preferred universities, reducing the private financial cost of tertiary education. Secondly, the truncation of student choices would considerably diminish the observed low graduation rates and low interest by students, as they would declare universities which are within their field of interests. Even though it might violate strategy-proofness, it could be a realistic and easy to implement measure.

8. Conclusion

In this paper, we dealt with the application of matching theory in university admissions in Greece. By analysing the theoretical background of matching models and the prevalent matching mechanisms, we focused on the application of the DA algorithm in Greece and how the proposed government reforms, namely the introduction of a weighting factor on student choices and a location-based criterion, would affect the properties of the matching mechanism. Introducing a weighting factor would violate stability and strategy-proofness of the matching mechanism leading to a significantly wasteful final matching with a number of students being unallocated to universities, whereas the location-based criterion would maintain the desirable properties of the algorithm and would contribute towards alleviating a proportion of the financial burden of families sending their children to study away from home.

We, therefore, maintain that the weighting factor should not be implemented as part of the proposed set of reforms and that instead, the Ministry of Education consider the truncation of student choices to 10 universities as an alternative measure. Such a measure would maintain stability in the matching mechanism, albeit not strategy-proofness, and it would be easier to implement and simpler to effectively explain to families and their children. This measure could be combined with the location-based criterion to address the empirical drawbacks observed in university admissions.

The lack of a detailed clarification of the proposed reforms by the Ministry of Education and the lack of available data for a greater number of years may potentially limit the validity of the results of this study. As suggestions for further research, an experimental study on the effects of placing a quota on student choices in Greece on different student classes (e.g. low vs. high-income) could shed light on how different classes strategize or optimize differently and how different strategic decisions lead to different allocation outcomes.

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