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A Proposed Mechanism for the Iranian Model of Kidney Donation (A Comparison of the Iranian and Roth's Models)

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Abstract

Optimal resource allocation by means of the price mechanism is one of the main duties of the economics. Optimum allocation is sometimes realized not through the price mechanism, but via assignment algorithms due to an insufficient number of agents on either side of the exchange. Facing the same problem, the kidney market may be considered as a type of market failure that calls for market design. Indeed, such design is regarded as a solution to the problem. Although the current model of organ transplants for non-relative living donors in Iran brings patients certain benefits, it suffers from serious weaknesses that require revisions. The present study aims to analyze the kidney market using a matching theory, which is a subset of market design. Then a model is developed in a test market for the research sample in Hamadan Province in 2015. Eventually, recommendations are made to modify the Iranian model of kidney donation. Despite Roth's model, the proposed model is based on two-sided matching. In this regard, information on 40 kidney suppliers and demanders were recorded in a clearinghouse. Subsequently, agents' preferences on either side of the market (i.e. patients and donors) were ranked based on blood-type, tissue, duration of disease, age, and gender compatibility. Applying the proposed model to the research sample, the results showed that 19 out of 20 pairs gained access to stable allocations.

Keywords: Mechanism Design, Market Design, Matching Theory, Kidney Exchange Model, Iranian Model of Kidney Donation, Assignment Algorithm.

JEL Classification: C79, D89, C71, C78.

1. Introduction

Kidney undersupply, despite increasing demand, is one of the major problems of End Stage Renal Disease (ESRD) patients in the world.

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Thus, some economists believe that it is the duty of economics to solve the problem so that they tried to create this missing market via market design and to connect supply and demand, From the viewpoint of these economists, some commodities, despite the fact that supply and demand are not formed, or if they are formed, fail: The failure of the market describes a situation in which the supply and demand forces in the resource market do not effectively allocate resources. In connection with the market failure, there are two old and new theory of market failure. The old theory, market failure caused by economy returns of scale, uncertainty and externalities (Layard and Walters, 1987). In new theory, market failure is based on high transaction costs and the existence of asymmetric information. In relation to some markets, there are several types of market failure:

Thin

The dispersion of market participants, low supply and demand, the lack of proper and appropriate communication between the parties, and the lack of mutual awareness of the actual preferences of the participants can be one of the main factors in market failures and lack of market formation.

Congestion

In this case, a large number of suppliers and demanders rush to the market to trade.

Safe

In this type of failure, suppliers and demanders do not trust their characteristics and cannot act on their own data, and this uncertainty will break the market. The kidney market is a real example of this type of market, which is not formed due to its thin (Roth, 2012).

Patients with kidney failure demand renal transplantation. To meet this demand, kidneys should be supplied in the market. Kidneys are supplied from two sources: 1) cadaveric kidneys donors, and 2) living donors.

For example, there were a number of 55,300 ESRD patients in Iran in 2015 while only 1200 patients could receive renal transplantation due to a lack of suitable kidney donation or difficulties of delivering a live kidney to the right patient (Dialysis Almanac, 2016). In 2003 there were 8,665 transplants of deceased donor kidneys for the approximately 60,000 patients waiting for such transplants in the U.S. While waiting, 3,436 patients died. There were also 6,464 kidney transplants from living donors (Roth, S. U., 2005).

To alleviate the imbalance in the kidney market, various countries have tried to draw upon different models for kidney transplantation over the last 30 years. One of the common models used in some western countries is generally referred to as the Kidney Exchange Model, or, alternatively, the American Model. This model includes patient-donor pairs in which donors are incompatible with patients. The donors are often patients' relatives willing to donate to their dear ones; however, they cannot do so due to blood or tissue incompatibilities. The present study aims to provide a mechanism to modify the Iranian Model of Kidney Donation (IMKD) based on market design theory and assignment algorithm. Paired kidney exchange is a solution to this problem, which was proposed in 1986 by Rapoport. (Rappaport, 1968). In 1991, the first paired kidney exchange took place in South Korea and then a few years in Europe and a year later, in 2000, the first paired kidney exchange took place in the United State. After that, the paired exchange grew rapidly and, with advanced algorithms, managed to increase the number of transplantation so that in the United States, in the third quarter of 2010, the number of paired transplantations increased to over 1,000 (UNOS [1], 2011). In the decade, the solution to the problem of supply shortages was the focus of a group of economists, which was the product of the emergence of market design theory.

This research seeks to propose a mechanism based on market design theory, a model offer for modifying the Iranian model of kidney donation. The structure of this research is as follows: In the second part, Iran's kidney donation model is described and in the third part, the literature review, which includes limited studies in Iran and major studies of Roth and his colleagues abroad, is expressed. Then, theoretical foundations and the pattern of matching and characteristics of blood groups are discussed. Modeling and estimating the model will be presented in the fifth section. Finally, conclusions and

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[1] UNOS. www.optn.org. (Accessed 2011, February 1)

recommendations will be addressed.

2. Iran’s Kidney Donation Model

IMKD is an alternative model currently in use, which is proposed to alleviate the problem of kidney undersupply. IMKD dates back to Iran-Iraq war when the country suddenly faced the shortage of dialysis machines with the increasing number of patients with renal failure. At the time, the patients were sometimes doomed to death. Lucky patients would receive kidneys from relatives or scarcely from foreign brain-dead patients. Still, kidney transplantation was insufficient for the growing number of patients in Iran. To tackle the problem, advice was sought from Grand Ayatollahs, as the supreme source of religious guidance, as to their verdict on selling kidney. The verdict authorized the trade providing that it did not entail any harms to the donor.[1]In 1988, the government introduced the LURD program, the adoption of the program during the 8-year war was an achievement for patients who no access to dialysis, and for the government with limited budget to set up new dialysis centers and expanding or maintaining existing ones. At the end of 1996, the "gift of Altruism or Rewarded Gifting" program was approved by the Board of Ministers, according to the bill, the government paid a donation to the donor (mazde,2012). The number of kidney transplants rapidly increased, so that by 1999, the kidney transplant waiting list was removed (Ghods, 2002; Ghods et al., 2001). At the end of 2005, a total of 19,609 kidney transplants were performed (3421 from living-related donors, 15,365 from living-unrelated donors, and 823 from deceased donors) (Ghods and Savaj, 2006).

Gradually, no one would donate a kidney for free with the escalating costs. Thus, a financial relation developed between the compatible donor and recipient who were then required to register with the Kidney Foundation of Iran in order to curb the prices within a reasonable limit

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[1] What is the verdict on selling kidney.
Short answer: it is not admissible to remove a part of living human body for transplantation when it causes a serious harm to the donor (e.g. hand, eye, etc.). However, when it does not entail a serious harm to the living donor (e.g. a piece of skin, spinal cord, or a kidney when the other kidney is healthy), donation is permissible providing that the donor gives his express consent (when he is not a child or lunatic). Otherwise, it is by no means permissible. When donation is permissible, the donor may ask for the price of the donated limb.

and avoid the formation of a black market.[1] Donors who are willing to sell their kidneys should also register with the foundation. Based on blood type and price agreements, the foundation introduces such donors to the registered recipients for tissue and other tests.

Although the Iranian model has some benefits but it has many drawbacks, which include:

The first: Since in the process of organ donation, the recipient and the recipient will know each other then there will be the possibility of a transaction between them. So, in fact, the organ donator does not donate transplantation, but it sells it to a person.

The second: Most donors do not have a good financial foundation as studies show that 84 percent of kidney donors are so poor (Ghods and Savaj, 2006).Also, transplant program from unrelated donations had a negative effect on the number of transplants from the related donations and this program reduced the number of such transplantations. (ghods,2000).

The third: The black market created by dealers and kidney purchase by those who have monetary resources call for ethical revisions in the IMKD (Mahdavi Mazdeh, 2012).

The four: IMKD generally relies on financial rewards so that it does not bear any non-financial motivations (Pazhuhi, 2014).

Ghods & Savaj (2006) is one of the most recent articles is trying to support the system by highlighting the benefits and responding to some critics. Data show that in 2006 1858 kidney transplants have been performed in Iran. 13% and 12% of these transplants has been achieved, respectively, from cadaveric and living related renal donations sources respectively and the other 75% was from living unrelated renal donations (Pondrom, 2008).

3. Literature Review

The Noble Prize in economic sciences was awarded to Lloyd Stowell Shapley and Alvin Elliot Roth in 2012 as a tribute to the Theory of Stable Allocations and the Practice of Market Design. Although conducting independent studies, Shapely and Roth both worked on the

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[1] Currently, the foundation gets 140,000,000 Rials from the recipient to pay the donor after the transplantation is done. Subsequently, the foundation refers the donors to the Governorates to receive an extra 10,000,000 Rials bonus for their merciful act.

same subject and addressed the same issues such as how can a relationship and compatibility be created between hospitals’ need for recruiting doctors and doctors’ need for job opportunities or how could student preferences for school selection be matched with school preferences for student selection. It was the authority of market design to answer these questions. Matching theory is a subset of market design and market design is a subset of mechanism design, the task of the theory of designing a mechanism is to create the optimal selection in the rules of the game. That is what the game theory has given it. A limited number of studies have already addressed the issue.

In early 1900s, students of medical sciences sought in U.S to find jobs at hospitals before completing their studies at university. On the other hand, the hospitals were competing to recruit the best job applicants. By 1940, the majority of students graduated from universities while they had already been employed for two years; that is, long before the hospitals could have identified the best applicants assuredly (Roth, 1991). This was evidently suboptimal because these premature job offers were made while the hospitals lacked sufficient information on doctors’ skills. Later on, new problems emerged as doctors began to marry their own colleagues, and doctor couples wished to work at the same hospital. Still, many couples did not apply for jobs because they thought it was almost unlikely to get jobs at the same hospital. Thus, they preferred to live together. To alleviate these problems, Roth and colleagues designed a new algorithm in 1995 that has been in use since 1997. The algorithm is used to employ over 20,000 doctors in hospitals in the United States every year, 10 percent of whom are doctor couples (Roth, 2012).

In 2006-2007, the issue of student assignment was raised in New York as the existing mechanism failed to work efficiently and stably. Thus, a new mechanism was employed that yielded stable allocations. In such markets, students have a list of their favorite schools, and schools have a list of their preferred students based on such criteria as GPA, standardized test scores, race, gender, family income, place of residence, etc. The ultimate goal is to assign students to various schools such that capacity constraints in schools are given due consideration, and both students and schools receive their preferences as far as possible. More importantly, student distribution among schools should be stable as much as possible so that no school or student could change the matching independently. The most commonly used location assignment mechanism is the one developed in Cambridge, Boston, in 1980s. The mechanism aims to allocate students to the first priority as far as possible In New York, more than 90,000 students a year must be allocated to more than 500 high schools. In the old system, only about 50,000 students initially received suggestions, about 17,000 of them received several suggestions. And about 30,000 students had been assigned to a school that was not included on their choice list. When in New York City adopted a clearinghouse for high school matching in 2003, the congestion problem was solved; only about 3,000 students a year were replaced Administratively.

Haddadimoghadam (2015) used the theory of market design to study the Iranian medical labor market in the private sector. He observed that physician unemployment results from inadequate distribution of workforce. That is, there is surplus of medical workforce (oversupply) in large cities while there is excess demand (undersupply) is small cities. This particular type of unemployment culminates in market failure. The solution is market design. He then used a test market to develop a model and prescribe remedies to the labor market.

The most important application of market design in the past decade has been to the kidney market in the United States[1]. Inherent problems in the kidney exchange market include long waiting list for transplantation, impossible exchange at one and the same time due to incompatibilities arising from the immune system, which leads to market failure. It is thus necessary to develop a matching model as Roth and colleagues did after years of experimentation to alleviate the problem. They have succeeded to save thousands of lives. In Roth's model, each cycle has a maximum length of 3, and it is maintained that two- and three-way exchanges exert considerable impact on the number of kidney transplants while larger than three-way exchanges have less impact on efficiency (Roth, 2005). It is imperative to undertake market design (kidney exchange mechanism) as kidney patients suffer acute problems while long waiting time often results in their death.

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[1] The Netherlands, South Korea, Australia, Britain, India, Greece, Canada, Portugal, Austria, France, Spain, Poland, Argentina, Italy and Turkey use the Roth model.

4. Theoretical Foundations

Market design is concerned with the creation of a venue (pure venue) for the buyers and sellers and the definition of a legal (institutional) framework as to how to do the exchange. It is applicable in case of market failure (Roth, 1999). Market design addresses a plethora of questions in the field of economics some of which are mathematical questions and some are related to institutions (Roth, 2012).

The present study addresses matching theory which is a subset of market design.

4.1 Matching Theory

"Matching" is part of the economics that places on the issue of who gets what, particularly when the goods are heterogeneous and indivisible; For example, how can a relationship and compatibility be created between hospitals' need for recruiting doctors and doctors' need for job opportunities or how could student preferences for school selection be matched with school preferences for student selection, etc.[1]. In this section, we study that how matching markets create efficient or stability matches (roth,2007). In this theory, price mechanism does not offer solution to the problem of resource allocation. Rather, allocation is based on suppliers and demanders' conditions. Based on the proposed algorithm, ranked preferences replace and act as price system. The model has two modes:

1- The two-sided matching Models is a situation in which parties, the supply side and the demand side match to its preferences. Two sided matching model consists of two sets of agents, set 1 $=\{m_1, m_2, \dots, m_n\}$ and set 2 $=\{w_1, w_2, \dots, w_p\}$, each of whom has preferences over the agents on the other side.

2- One-Sided Matching Models was introduced by Shapley and Scarf (1974). The kidney market is in this group. Using the Top Trading Cycles algorithm (TTC[2]), stable allocations are found. Allocations are stable if

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[1] Matching theory is based on GALE and SHAPLEY model. they proposed a simple model of two-sided matching, in which agents each had preferences over agents to whom they might be matched in the other set. They proposed an algorithm that works by having agents on one side of the market make proposals to agents on the other, in order of preference (Molabeigi, 2017).

[2] There are at least one cycle in this mechanism. The cycle is a list of the following factors:(i1, i2, i3, ..., ik). Each agent is referenced to the next agent in the list and the ik agent is introduced

any individual or pairs do not block those. If in a matching, agent prefers to be alone to being matched, matching is blocked.

5. Status of Kidney Patients in Iran

By the end of 2015, there were a number of 55,000 ESRD[1] patients in Iran who were under treatment with renal replacement therapy. With regard to the 6 percent annual growth in ESRD patients and 1.3 percent population growth in Iran, one may conclude that it will be a challenge for the country to provide medical care for the patients and bear the costs. Thus, neither is kidney transplantation in Iran like that in western countries where it is typically from living related donors, nor is there a real kidney market to assign the supply price and demand mechanism. For example, most of the transplant is from unrelated donors who donate their kidney Because of reward so that by the end of 2005, a total of 19,609 renal transplants were performed (3421 from living related, 15,356 from living-unrelated and 823 from deceased donors) (Ghods and Savaj, 2006). Therefore, it seems necessary to develop an algorithm different from those in the western countries.

5.1 The Kidney Exchange Model

Kidney market has A triple sides (*K*,*T*,*R*): suppliers (*K*), demanders (*T*), and participants' preferences (*R*). The variable of time is excluded from this study so that the analysis is done in the static mode. The function can take various forms based on specific assumptions of the model. The proposed model adopts the following assumptions: discrete sets of kidney suppliers and demanders including all demanders $= \{t_1, \ldots, t_p\}$, all suppliers $\mathrm{K} = \{\mathrm{k}_1, \ldots, \mathrm{k}_\mathrm{q}\}$, and either side of the market has complete preferences transferable to the factors on the other side of the market. Each and every matching process is a subset of $T \times K$ set. In the matching process, binary sets will be matched based on honest (non-strategic) preferences in order to design market and avoid market failure, which include the ordered pairs of suppliers and demanders represented as (t, k). The basket of preferences for every t and k include $R = (R_m)_{m \in T \cup K}$. R_t is the preferences equation for the set $T \cup$

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to i1. In each given exchange cycle, the process continues with the remaining factors. (Molabeigi, 2017).

[1] End Stage Renal Disease

$\{t\}$; R_k represents preferences equation for the set $T \cup \{k\}$; P_m is the strong preferences equation derived from R_m; and $i\ P_m\ j$ denotes that $i\ P_m\ j$ but not $j\ R_m\ i$ holds true. If the agent $m \in T \cup K$ prefers not to sell his good to the agent j (does not match with the agent), then $m\ P_m\ j$ will be in effect. Thus, j's good is not acceptable to *m* so that *m* prefers to match with itself. Consequently, j is considered unacceptable to m.

Assuming the demanders' list of preferences $p\ (t_i)$ and suppliers' list of preferences $p\ (k_i)$ to be as follows:

$k_1 \geq k_2 \geq k_3 \ldots \geq k_q$ $\qquad$ $t_1 \geq t_2 \geq t_3 \ldots \geq t_q$

$p\ (t_i) = t_1, t_2, t_3 \ldots, t_q$ $\qquad$ $p\ (k_i) = t_1, t_2, t_3 \ldots, t_q$

Then in some points, an individual (either legal or natural) may prefer to remain unmatched in this process due to specific game (matching) conditions. Thus, his preferences may be defined as follows in this model:

$p\ (t_i) = k_4, k_3, \ldots, t_i, \ldots$

That is, patient i-th prefers K_4 to K_3 so that K_4 has priority in his list of preferences. However, we may arrive at a point in this list where he prefers self-matching to other options. A matching μ is blocked by the individual $m \in T \cup K$ when m prefers not to enter into the exchange through the $\mu\ (m)$ matching, hence $m\ P_m\ \mu\ (m)$. A matching μ is blocked by the pair $(t, k) \in T \times K$ when either side of the exchange prefers another agent under the matching μ, that is $K\ P_t\ \mu\ (t)$ and $t\ P_k\ \mu\ (K)$. In this case, $\mu(k) = k$ and $\mu(t) = t$.

The main point in matching is stability. As Roth contends, the main concept in understanding the success or failure of market institutions is the stability of allocations[1] (Roth, 1991). If a matching is designed in a centralized or decentralized manner but lacks stability, it will not be applicable to solving complicated optimization problems and market design (Roth, 2000).

5.2 Analysis of the Model

In the present study, a number of 20 donor-patient pairs of different blood types were selected randomly after due consultation with the Kidney Foundation of Iran[2]. The process of selection was such that after

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[1] Theorem 3: no stable matching procedure for the general matching problem exists for which truthful revelation of preferences is a dominant strategy for all agents (Roth, 1982a).

[2] In a research in 2003, Roth studied a number of 12 pairs but has also examined up to 25 pairs in other studies.

an initial study on the patients supported by the Foundation, less than 100 patients were found to have the chance for inclusion. Considering financial limitations and drawing upon Roth's methodology, forty participants (20 pairs) were selected using systematic random sampling. Overall, the number of patients and donors were as follows based on blood type:

Patients t_1, t_2, t_3, t_4, t_5, t_6, t_7 are with blood type O, patients t_8, t_9, t_{10}, t_{11}, t_{12} are with blood type A, patients t_{13}, t_{14}, t_{15}, t_{16}, t_{17} are with blood type B, and patients are t_{18}, t_{19}, t_{20} with blood type AB.

Donors K_1, $K_{2,}$ K_{15}, K_{16}, K_{19}, K_{20} are with blood type A, donors K_3, $K_{4,}$ K_{10}, K_{11}, K_{12}, K_{17} are with blood type B, donors K_7, $K_{8,}$ K_9, K_{13}, K_{14}, K_{18} are with blood type O, and donors K_5, K_6 are with blood type AB.

Arrangement of preferences

1. Blood-type compatibility: kidney transplantation is unlikely when the pairs are incompatible. As shown in Table 4, a patient of blood type O is compatible with a donor of blood type O. A patient of blood type A is compatible with a patient of blood type A and O. A patient of blood type B is compatible with a patient of blood type B and O. A patient of blood type AB is compatible with the donors of blood type A, B, AB and O.

Table 1: Cross Matching by Blood Type

Sides		**Donor**			
	Blood types	O	A	B	AB
Patient	O	▶			
	A	▶	▶		
	B	▶		▶	
	AB	▶	▶	▶	▶

Source: Research data

2. Tissue compatibility is key to kidney transplant acceptance or rejection. There should be blood-type compatibility between donor and recipient in kidney transplants. When blood-type compatibility is ensured, tissue identification test is conducted to examine donor-recipient genetic tissue similarities. Before transplantation, cross-matching test is carried out which involves mixing donor's and patient's

blood samples. The test is conducted to ensure that the blood lacks any cytotoxic antibodies that cause transplant rejection.

3. How long the patient has been on the waiting list: the less the waiting time is and the sooner the transplant is done, the better.

4. Age: the younger the donor, the better. the healthier the donor, the better.

5. Patient’s relatives: transplant acceptance is more likely when the donor is an immediate relative (e.g. parents or siblings).

6. Donor’s gender: all things being equal, male donors are preferable to females.

Patients’ preferences for compatible kidneys and the waiting list are as follows.

Table 2: Examining Tissue Compatibility by Patients’ Blood Type

blood type O							**blood type A**					**blood type B**					**blood type AB**		
t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}	t_{12}	t_{13}	t_{14}	t_{15}	t_{16}	t_{17}	t_{18}	t_{19}	t_{20}
k_9	k_{14}	k_9	k_{13}	k_7	k_{18}	k_7	k_{19}	k_{19}	k_2	k_2	k_2	k_{12}	k_{17}	k_9	k_{14}	k_{12}	k_5	k_5	k_6
k_{14}	k_8	k_8	k_{18}	k_{18}	k_7	k_{18}	k_{20}	k_2	k_{19}	k_{20}	k_{19}	k_{17}	k_{12}	k_{12}	k_9	k_7	k_6	k_6	k_5
k_8	k_9	k_{14}	k_7	k_{13}	k_{13}	k_{13}	k_2	k_{20}	k_{20}	k_{19}	k_{16}	k_9	k_9	k_{17}	k_7	k_{11}	k_9	k_{20}	k_{14}
k_{18}	k_{13}	k_{18}	k_9	k_9	k_{14}	k_{14}	k_{16}	k_{16}	k_9	k_9	k_{20}	k_{14}	k_{14}	k_8	k_{12}	k_9	k_{20}	k_9	k_8
k_{13}	k_{18}	k_7	k_{14}	k_8	k_9	k_8	k_9	k_9	k_{16}	k_{14}	k_{14}	k_8	k_8	k_{14}	k_{18}	k_{17}	k_{14}	k_8	k_{20}
k_7	k_7	k_{13}	k_8	k_{14}	k_8	k_9	k_{14}	k_{14}	k_{14}	k_{16}	k_9	k_{18}	k_{18}	k_7	k_{17}	k_{14}	k_8	k_{14}	k_9
-	-	-	-	-	-	-	k_8	k_8	k_{18}	k_8	k_8	k_{13}	k_7	k_{18}	k_8	k_3	k_{19}	k_{18}	k_{19}
-	-	-	-	-	-	-	k_{18}	k_7	k_8	k_{18}	k_{18}	k_7	k_{13}	k_{10}	k_{13}	k_8	k_{18}	k_{19}	k_{18}
-	-	-	-	-	-	-	k_7	k_{18}	k_7	k_7	k_7	k_{10}	k_{10}	k_{13}	k_{10}	k_4	k_{17}	k_{12}	k_{17}
-	-	-	-	-	-	-	k_{13}	k_{13}	k_{13}	k_{13}	k_{13}	k_3	k_4	k_{11}	k_4	k_{10}	k_{13}	k_{13}	k_{13}
-	-	-	-	-	-	-	k_{15}	k_1	k_1	k_{15}	k_1	k_4	k_3	k_3	k_{11}	k_{13}	k_{12}	k_{17}	k_{12}
-	-	-	-	-	-	-	k_1	k_{15}	k_{15}	k_1	k_{15}	k_{11}	k_{11}	k_4	k_3	k_{18}	k_2	k_2	k_{11}
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	k_{10}	k_3	k_2
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	k_{11}	k_{10}	k_{10}
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	k_3	k_{11}	k_7
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	k_7	k_{16}	k_3
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	k_{16}	k_7	k_{15}
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	k_{15}	k_{15}	k_{16}
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	k_4	k_1	k_1
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	k_1	k_4	k_4

Source: research data

In table 2, patients’ preferences are illustrated based on the abovementioned arrangement. For example, donors of the ninth, fourteenth, eighth, eighteenth, thirteenth and seventh pairs are tissue- and blood-compatible with patient 1. Of these donors, donor of the ninth pair has priority over donor of the fourteenth pair, the fourteenth donor over the eighth donor, the eighth donor over the eighteenth donor, the eighteenth donor over the thirteenth donor, and the thirteenth donor over the seventh donor, respectively. Other preferences are similarly illustrated in Table 2.

Table 3: Examining Tissue Compatibility by Donors' Blood Type

k_1	k_2	k_3	k_4	k_5	k_6	k_7	k_8	k_9	k_{10}	k_{11}	k_{12}	k_{13}	k_{14}	k_{15}	k_{16}	k_{17}	t_{18}	k_{19}	k_{20}
t_{11}	t_8	t_{16}	t_{16}	t_{18}	t_{19}	t_4	t_4	t_3	t_{16}	t_{13}	t_{16}	t_4	t_3	t_8	t_{10}	t_{14}	t_5	t_{10}	t_{11}
t_8	t_{10}	t_{13}	t_{15}	t_{19}	t_{18}	t_3	t_2	t_4	t_{13}	t_{16}	t_{13}	t_2	t_4	t_{11}	t_8	t_{16}	t_4	t_8	t_8
t_{10}	t_{11}	t_{14}	t_{13}	t_{20}	t_{20}	t_5	t_3	t_5	t_{14}	t_{15}	t_{15}	t_5	t_5	t_{10}	t_{11}	t_{13}	t_3	t_{11}	t_{10}
t_{19}	t_9	t_{15}	t_{14}			t_2	t_5	t_2	t_{15}	t_{14}	t_{14}	t_3	t_7	t_{19}	t_{18}	t_{15}	t_2	t_{19}	t_{18}
t_{18}	t_{12}	t_{17}	t_{17}			t_7	t_1	t_7	t_{17}	t_{17}	t_{17}	t_7	t_2	t_{18}	t_{19}	t_{19}	t_7	t_{18}	t_{19}
t_{20}	t_{19}	t_{19}	t_{18}			t_1	t_7	t_1	t_{20}	t_{19}	t_{20}	t_1	t_{11}	t_{20}	t_{20}	t_{17}	t_{10}	t_{20}	t_{20}
t_9	t_{20}	t_{20}	t_{20}			t_{11}	t_9	t_{11}	t_{19}	t_{20}	t_{19}	t_9	t_1	t_9	t_{12}	t_{20}	t_9	t_9	t_9
t_{12}	t_{18}	t_{18}	t_{19}			t_9	t_{11}	t_9	t_{18}	t_{18}	t_{18}	t_{11}	t_9	t_{12}	t_9	t_{18}	t_{11}	t_{12}	t_{12}
						t_{10}	t_8	t_{10}				t_8	t_{10}				t_1		
						t_8	t_{10}	t_8				t_{10}	t_8				t_{14}		
						t_{14}	t_{14}	t_{14}				t_{14}	t_{14}				t_8		
						t_{13}	t_{13}	t_{13}				t_{13}	t_{13}				t_{13}		
						t_{16}	t_{16}	t_{16}				t_{16}	t_{20}				t_{20}		
						t_{19}	t_{20}	t_{19}				t_{20}	t_{19}				t_{16}		
						t_{20}	t_{19}	t_{20}				t_{19}	t_{16}				t_{19}		
						t_{15}	t_{15}	t_{15}				t_{15}	t_{17}				t_{15}		
						t_{17}	t_{17}	t_{17}				t_{17}	t_{15}				t_{17}		
						t_{18}	t_{18}	t_{18}				t_{18}	t_{18}				t_{18}		
						t_6	t_6	t_6				t_6	t_{12}				t_6		
						t_{12}	t_{12}	t_{12}				t_{12}	t_6				t_{12}		

Source: Research data

5.3 Number of Transplants without Mechanism

As shown in Table 2, incompatible patient-donor pairs are as follows. The incompatibility is because patients t_1, t_2, t_3, t_4, t_5, t_6, t_{10}, t_{11}, t_{12}, t_{15}, t_{16} are of blood-types O, O, O, O, O, O, A, A, A, B, and B, respectively, while their donors are of blood-types A, A, B, B, AB, AB, B, B, B, A, and A, respectively.

The pairs with patient-donor blood and tissue compatibility are as follows:

$(t_7, k_7) – (t_8, k_8) – (t_9, k_9) – (t_{13}, k_{13}) – (t_{14}, k_{14}) – (t_{17}, k_{17}) – (t_{18}, k_{18}) – (t_{19}, k_{19}) – (t_{20}, k_{20})$

In other words, 11 pairs are blood-incompatible from among a total of 20 pairs. In the absence of matching mechanism, these patients cannot receive kidneys from their respective donors who will then fail to donate kidney. Thus, only would 9 pairs proceed with kidney transplantation.

5.4 Number of Transplantations with the Designed Mechanism

The designed mechanism begins such that a kidney demander is referred to a donor ranking first in his list of preferences. If the kidney recipient fails to match with his first choice, he will have to match with the second preferred donor. The process will continue the same for the third preference and other choices until the demander gains a tentative matching or until all his choices are rejected. Now, the matching process will be applied to a number of 20 patients and 20 donors as follows.

Based on Table 2, patient 1 is matched to donor 9 that takes the first priority in the patient’s ranked preferences. Since every patient receives only one kidney, the donor may be said to have matched to the patient tentatively. Then patient 2 is matched to donor 14 that is his first priority. Patient 2 is also matched to the donor tentatively. Subsequently, patient 3 is matched to donor 9 that is his first priority. As can be seen, donor 9 was previously matched to patient 1; however, the donor prefers patient 3 to patient 1 with whom he was matched earlier tentatively. Thus, patient 1 is excluded, and patient 3 is tentatively matched to donor 9. Having been excluded from his tentative matching, patient 1 should resume the matching process again. Patient 1 is then referred to donor 14 as his second priority. As can be seen, donor 14 was previously matched to patient 2, but he still prefers patient 2 to patient 1 with whom he was tentatively matched earlier. Having been excluded from the matching again, patient 1 should resume the matching phase. Eventually, patient 1 is referred to donor 8 as his third priority and will finally match to the donor. The process takes place for all patients in the same manner as illustrated in Table 4.

In the final phase, tentative matchings will be finalized. It, however, should be noted that no patient or donor will get a final matching in the matching process unless all demanders' list of preferences are examined for ensuring the best tentative matching. With the designed mechanism, nineteen pairs will have successful kidney exchange. Patients 1, 2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, and 20 match to donors 9, 10, 17, 18, 19, 5, 1, 3, 13, 15, 16, 4, 2, 20, 12, 14, 7, 8, and 11, respectively.

The algorithm is solved in two ways. It makes a difference whether the offer is from demanders or suppliers. Since the purpose is to maximize patient welfare, the offer should be on the part of the demanders. As can be seen, when the offer is from patients, the number of updates or steps is limited to 19 as illustrated in Table 4. The maximum number of updates in these algorithms is $n^2 - 2n + 2$ where *n* is the number of supplier or demander (Gale & Shapely, 1962).

Table 4: Matching Phases of Kidney Market Design Mechanism in the Selected Sample of Demanders (Numbers Represent Patients)

STEPS	k_1	k_2	k_3	k_4	k_5	k_6	k_7	k_8	k_9	k_{10}	k_{11}	k_{12}	k_{13}	k_{14}	k_{15}	k_{16}	k_{17}	t_{18}	k_{19}	k_{20}
Round 1		10,11,12			18,19	20	5,7		1,3,15			13,17	4	2,16			14	6	8,9	
Round 2		10,9			18	19,20	5,17		3,16			13,15	4	1,2			14	6,7	8,12	11
Round 3		10			18,20	19	5,16,6	1	3		17	13	4	2		12	14,15	7	8	11,9
Round 4		10			18	19	5	1,15	3		17	13،16	4,6	2,20		12,9	14	7	8	11
Round 5		10			18	19	5	1,20	3,9		17	16	4	2,15,6		12	14,13	7	8	11
Round 6		10			18	19	5,15	1	3,6,13		17	16	4	2,9		12	14	7	8	11
Round 7		10			18	19	5	1,6,9	3,20		17	16	4	2,13		12	14	7,15	8	11
Round 8		10			18	19	5,9	1,13	3	15	17	16	4	2		12	14	7	8,20	11
Round 9		10			18	19	5	1	3	15	17	16	4	2		12	14	7,9,13,20	8	11
Round 10		10			18	19	5	1	3	15	17	16	4,13,19	2		12	14,20	7	8	11
Round 11	9	10			18	19	5,13	1	3	15	17	16	4,20	2		12	14	7	8	11
Round 12	9	10			18	19	5	1	3	13,15	17	16	4	2		12	14	7	8	11
Round 13	9	10			18	19	5	1	3	13	17,20	16	4 ,15	2		12	14	7	8	11
Round 14	9	10			18	19	5	1	3	13	17,15	16	4	2		12	14	7	8	11
Round 15	9	10			18	19	5	1	3	13,20	15	16	4	2		12	14	7	8	11
Round 16	9	10			18	19	5,20	1	3	13	15	16	4	2		12	14,17	7	8	11
Round 17	9	10	20		18	19	5	1	3	13	15	16	4	2,17		12	14	7	8	11
Round 18	9	10	20,17		18	19	5	1	3	13	15	16	4	2		12	14	7	8	11
Round 19	9	10	17		18	19	5	1	3	13	15	16	4	2	20	12	14	7	8	11

Source: Research data

A matching μ is blocked by an individual t if t prefers being single to being matched with μ(t), i.e. t $>_t$ μ(t). A matching μ is blocked by a pair of agents (t,k) if they each prefer each other to the partner they receive at μ, i.e. k $>_t$ μ(t) and t $>_k$ μ(k). A matching μ is stable if it isn't blocked by any individual or pair of agents[1]. The designed mechanism is a mechanism whose results have a stability property, because the preferences lists of all applicants to achieve the best matching will be examined. Since in the process of matching, no applicant will be able to achieve its final matching unless the preferences lists of all applicants for the best matching have been examined. In other words, each patients applies to her first choice. Each donor tentatively assigns its kidney to its applicants one at a time in their priority order. Any remaining applicants are rejected. Each patient who was rejected in the previous step applies to her next best choice if donor remains. Mechanism assigns donors only tentatively at each step and patients with higher priorities may be considered in subsequent steps. That feature guarantees that mechanism is stable in the sense that there is no patient who loses a kidney to a lower priority patient and receives a less-preferred assignment.

In this mechanism, if a donor is preferable for the patient compared to the introduced donor, less preferred donor will be removed from the matching and an again attempt will be made to matching this donor and will begin again with his first priority, That's why the allocation is stable.

5.5 Comparison of Roth’s Model of Kidney Exchange with the Proposed Model

One-sided matching model is used in the western countries due to a ban on kidney trade. Thus, every patient and their donor, who is often a relative, should register at a clearing house. Then kidney exchange between donors and recipients is done by using advanced algorithms. Although this model helps match demanders and suppliers, it has the following drawbacks in practice.

1. When a patient has no donor, he has either to remain on the waiting list for a brain-dead donor or receive a kidney from an

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[1] In simple terms, we say that a matching is stable if it does not violate priorities and not waste any goods.

altruistic donor.

2. In Roth's model, the longer the exchange cycle, the more the exchanges. Still, one of the difficulties of this model is how to obtain an optimal cycle. Besides, the question is whether or not surgery is viable simultaneous to finding the optimal cycles.
3. Limitations associated with concurrency of surgical operations

One of the difficulties of kidney exchange is the limited number of doctors and healthcare specialists. For example, six concurrent surgeries are required in a three-sided exchange so that a large number of doctors and staff plus operation rooms are needed. The necessary concurrency of these surgical operations lies in the legal prohibition of contracting for kidney exchange. It is legally prohibited to make a contract whereby, for example, you receive a kidney today, and in return, you donate a kidney to a patient tomorrow. Thus, the only way to ensure that your patient will receive a kidney in return for your donation of a kidney is to have the surgical operations simultaneously. Still, Roth and Sönmez (2007) have suggested solutions to the problem such as limiting the exchanges to two- and three-way exchanges ones. This, however, reduces the efficiency of the system since some exchanges are removed from the cycle (Ashlagi, 2012). Roth et al. (2012) have suggested altruistic kidney donors as an alternative. When there is an altruistic kidney donor in the market, the problem of concurrent surgeries will be solved by forming organ donation chains that begin with an altruistic donor. Under such circumstances, the altruistic donor may donate to patient A, and then patient A's relative may donate to patient B while patient B's relative donates to patient C, and so on. The important point is that the surgical operations need not be concurrent. This is because no catastrophe would occur if after the altruistic donor has donated a kidney to patient A, patient A's donor refrained from donating to patient B. Although this is a bitter event, patient B and his related donor are still in the kidney exchange market.

4. Uncooperative hospitals

Some hospitals tend not to introduce the so-called easy transplantations to the clearinghouse. They would only introduce patient-donor pairs who are difficult to match. Recent studies have been conducted on how to engage the hospitals in the game. Park (2010) showed that, with 11 patient-donor pairs and 2 hospitals, the number of transplantations increased by 50% as compared with when the exchanges were internally organized. The number of transplantations would increase by 300% with 22 hospitals involved. Thus, there must be incentives for the participating hospitals but punishment and fines for violating hospitals.

The above-mentioned drawbacks with the Roth’s model result from the fact that it is a one-sided matching approach so that only has one side of the market (patients) a list of preferences. However, the proposed model for Iran is a two-sided matching mechanism in which either side of the market (patients and donors) has a list of preferences. Thus, the Iranian model has fewer drawbacks than Roth’s because the majority of donors donate kidneys to receive donation bonus. Consequently, it is not necessary to have concurrent surgical operations and seek hospital cooperation.

5. Result

Increased number of kidney patients has resulted in increased demand for renal replacement therapy, hence the dramatic increase in kidney transplantation demand. Marked increase in demand, limited supply have led to new approaches to treatment in the world. Preventive measures should be taken by the healthcare management system in the first place. Secondly, disciplines other than medicine should engage in the disease control and cost reduction. Economics is a leading discipline designing mechanisms in kidney exchange.

The present study aimed to examine the problems of kidney market in Iran and provide functional procedures to address the issue. Although kidney trading is not illegal in Iran, the price mechanism may not optimally allocate the resources since the pricing is done by the government. Besides, dispersed market participants, limited number of suppliers and demanders, and lack of effective communication between the parties may lead to market failure or hinder market formation. Moreover, in the current model, both donor and recipient know each other in advance personally or are introduced together by active communities. Thus, the donor may ask for money from the recipient. Indeed, the donor does not donate an organ in such a system but sells it to the patient at a certain price. This cannot be an ethical model, though. To tackle the problem, a clearing house could be established where the data on donors and recipients are recorded in such markets. Following the processing of the data, patient-donor preferences are determined based on blood and tissue types as well as other factors. After prioritization of preferences, patient-donor pairs are matched through an assignment mechanism. The present mechanism was developed using market design theory and matching models. In this system, the data should be recorded such that donors can donate the organ without knowing the recipient.

The proposed model was developed based on two-sided matching. The algorithm resulting from this model can produce stable allocations for the patients. The proposed model was tested on a sample of 40 participants. Following the accumulation of the data and ranking kidney supplier-demander preferences in the clearinghouse, the algorithm could match 19 out of 20 patient-donor pairs through 19 steps.

References

Abdulkadiroglu, A., Parag, A., Pathak, A., & Alvin, E. R. (2009). Strategy-proofness versus Efficiency in Matching with Indifferences: Redesigning the NYC High School Match. *America Economic Review, 5*(99), 1954–1978.

Ashlagi, I., & Alvin, E. R. (2012) New Challenges in Multi-hospital Kidney Exchange. *American Economic Review Papers and Proceedings, 3*(102), 354-359.

Gale, D., & Shapely, L. S. (1962). College Admissions and the Stability of Marriage. *The American Mathematical Monthly, 69*, 9-15.

Ghods A. J., *Ossareh, S.,* & Savaj, S. (2001). Results of renal transplantation of the Hashemi Nejad Kidney Hospital–Tehran. Retrieved from https://europepmc.org/abstract/med/11512314.

Ghods A. J., Savaj, S., & Khosravani, P. (2000). Adverse Effect of a Controlled Living Unrelated Donor Renal Transplant Program on Living Related and Cadaveric Kidney Donation. *Transplant, 32*(3), 541- 551.

Ghods, A. J., & Savaj, S. (2006). Iranian Model of Paid and Regulated Living-Unrelated Kidney Donation. *Clinical Journal of American Society of Nephrology, 1*(6), 1136-1145.

Ghods, A. J. (2002). Renal Transplantation in Iran. *Nephrol Dial Transplant, 17*, 222–228.

Layard, P. R.G., & Walters, A. A. (1987). *Microeconomic Theory*. New York: McGraw Hill.

Mahdavi-Mazdeh, M. (2012). The Iranian Model of Living Renal Transplantation. *Kidney International, 82*, 627–634.

Molabeigi, J., Ebadi, J., Elāhi, N., & Amir Zargar, M. A. (2017). Designing a Mechanism for Kidney Exchange in Iran. *Quarterly Journal of Applied Economics Studies in Iran (AESI), 6*(24), 95-123.

Molabeigi, J., & Ebadi, J. (2017). *Mechanism Design for Kidney Exchange in Iran* (Doctoral Dissertation). University of Mofid, Tehran.

Pajouhi, A., Zahedi, F., Pajouhi, Z., & Larijani, B. (2014). Paid Living Kidney Transplantation in Iran: Rethinking the Challenges. *American Journal of Bioethics, 4*, 40-42.

Pondrom, S. (2008). Is the Iranian Paid Donation Model a Success or Not? *American Journal of Transplantation, 8*(3), 477-478.

Rapaport, F. T. (1986). The Case for a Living Emotionally Related International Kidney Donor Exchange Registry. *Transplant Procedure, 18*, 5-9.

Roth, A. E., Sönmez, T., & Ünver, M. U. (2005). Pairwise Kidney Exchange. *Journal of Economic Theory, 125*(2), 151-188.

Roth, A. E. (2012). The Theory and Practice of Market Design. *Retrieved from* https://bayanbox.ir/view/6646157809221867346/Roth-Shapley-920803.pdf.

---------- (2000). *Game Theory as a Tool for Market Design*. Boston: Kluwer Academic Publishers.

Roth, A. E., & Peranson, E. (1999). The Redesign of the Matching Market for American Physicians: Some Engineering Aspects of Economic Design. *American Economic Review, 89*(4), 748-779.

Roth, A. E., Sönmez, T., & Ünver, M. U. (2007). Efficient Kidney Exchange Coincidence of Wants in Markets with Compatibility-Based Preferences. *American Economic Review, 97*(3), 828-851.

Roth, A. E., & Sotomayor, M. (1992). *Two Sided Matching. Handbook of Game Theory with Economic Applications.* North Holland: Elsevier.

Roth, A. E. (1991). Game Theory as a Part of Empirical Economics. *The Economic Journal, 101(*404), 107-114.

Saidman, S. L., Roth, A. E., Sonmez, T. M., Unver, U., & Delmonico, F. L. (2006). Increasing the Opportunity of Live Kidney Donation By Matching for Two and Three Way Exchanges. *Transplantation, 81*, 773-782.
Simforoosh, N., Basiri, A., & Tabibi, A. (2014). Laparoscopic Donor Nephrectomy an Iranian Model for Developing Countries: A Cost-effective No-rush Approach. Retrieved from https://pdfs.semanticscholar.org/74cd/e06f3783450e0c7613aee69ef6b290b07acd.pdf.

Simforoosh, N., Bassiri, A., & Amiransari, B. (1992). Living-unrelated Renal Transplantation. *Transplant Procedure, 24*, 2421-2422.

Toulis, P., & Parkes, D. (2010). A Random Graph Model of Kidney Exchanges Optimality and Incentives. *Working Paper*, Retrieved from www.cs.toronto.edu/~eidan/papers/ec11-ptoulis-parkes.pdf.