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Nobel Prize Winners

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MEN AND MARKETS: ECONOMICS AS ENGINEERING SCIENCE*

Abstract

The 2012 Sveriges Riksbank Prize in Economics (Nobel Prize in Economics) was awarded jointly to Alvin E. Roth and Lloyd S. Shapley «for the theory of stable allocations and the practice of market design». With their works the two economists have laid the foundation for a new research field: market design.

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One of the most important tasks of markets and of social processes is to bring together two parties: Buyers and sellers, pupils and schools, students and universities, organ donors and organ receivers must find together. The design of these markets, i.e. the determination of rules and the shaping of institutions important for these markets, is the field of market design – the research field of Alvin Roth and Lloyd Shapley. They have worked with markets without prices. E. g. organs and study places are with good reason not being sold. In the 1960ies Shapley together with David Gale, who passed away in 2008, built the theoretical basis for such markets. Roth recognized in the 1990ies how this work could be used for ameliorating the functioning of real markets.

However, the transfer from theory to practice required a lot of adaptations – the models had to be adjusted, results from psychology and from behavioural economics had to be integrated, marketand market structures had to be tested in laboratories and in computer simulations. The interaction of these scientific elements characterizes the research field of market design, which nowadays goes far beyond the matching markets studied by Roth and Shapley. In energy markets, auction markets like eBay, for the distribution of telecommunication licences, for public procurements as well as for private acquisitions the results of market design are used with great success. But the transfer of results goes also the other way: The dealing with real problems gives many impulses for the research in economics [17].

Markets without prices – Matching Markets

The path-breaking work by Gale and Shapley from 1962 bears the title «College Administrations and the Stability of Marriage» [15]. The problem: Two groups – be it students and universities, pupils and schools, or women and men – want to find together. But not everybody can realize his or her first choice, because the number of study courses and school places is limited. There are many possibilities to design an allocation procedure. To bring e.g. pupils and schools together one could assign the pupils to the school in the district they live. An alternative would be that pupils send an application to schools, whereby schools which receive too many applications have to reject pupils. These pupils then must be placed to other schools.

The research question now is the following: Given these problems, how does a good allocation or matching mechanism look like? This question, however, cannot be answered without answering a second question: What defines a «good» matching mechanism? Gale and Shapley solved these two problems analytically. To understand their answer an example is useful: Suppose there are five women and five men who should be coupled. Each woman and each man have a certain preferential ordering about the persons of the other sex (e. g. woman *A* finds most attractive man *B*, then follows man *C*, …, but man A is inacceptableunacceptable). A matching mechanism brings the women and men together.

First, one has to define what a good matching mechanism is. One merit of the work of Gale and Shapley is that they developed the criterion of *stability* to answer this question: An allocation result is stable if there is no pair which likes to be together, but by using this mechanism does not come together. Furthermore, no person should build a pair with someone he or she finds inacceptableunacceptable. Or formulated otherwise: If e. g. man *A* prefers woman *B* to the one allocated to him, then it must be that woman B forms a couple which she prefers to man *A* – or woman *B* is without a partner and prefers this situation to the partnership with man *A*. If this is not the case, the result of the allocation mechanism is unstable. Because then man *A* and woman *B* would be better off, if they separate from their existing partners and form a couple.

Stability is a general solution concept in cooperative game theory. Cooperative game theory analyzes coalition building of players under the condition that every conflict within a coalition can be solved by binding agreements. Results are stable if no coalition can make its members better off by deviating from the result. The stability concept is related to the so called Nash equilibrium in non-cooperative game theory. There one speaks of an equilibriumequilibrium if no individual could be made better off by deviating [21]. Also a competitive equilibrium is under certain conditions stable, at least if the individuals bring along enough time and capabilities to calculate all options to do better in any coalition.

The Gale–Shapley Algorithm

After having defined the criterion of stability for simple matching markets, Gale and Shapley developed an effective allocation mechanism which satisfies this condition: the «Gale–Shapley algorithm». This mechanism runs in several rounds: First, every man goes to his preferred woman. If in this round several men approach the same woman, she can choose provisionally from this group the man she prefers. In the next round the men rejected go to their second choice. Therefore, it can happen that a woman has chosen provisionally a man in the first round and now in the second round one or several men come to her. The algorithm then allows that the woman chooses the most agreeable from the group of new men and the man from the first round. Therefore, it can happen that the woman rejects the man from the first round, because she has found in round 2 a better fit.

This procedure goes then into the next round. Rejected men go to the woman which ranks one step lower in their preferences. Women choose provisionally the man from the group coming to her which she prefers most. In this manner, men «work» themselves down in their preference order while women move up in their preference order. Formally one can show that this process comes to an end in finite time, and that the result is stable. Man *A* may consider a woman better than the one with which he forms a couple finally, but then it must be the case that this woman has a man whom she considers better than man *A*, because during the procedure she has had the possibility to form a couple with man *A*.

To use this algorithm in practice, a multitude of problems must be solved. One crucial problem is that one has to clarify whether the market participants have an interest to follow truly their preference ordering, or whether they could try to manipulate this process e. g. in going first to a partner which stands lower in their preference order. This question is answered by Alvin Roth in a paper published in 1982 [4]. Here he shows that in the Gale–Shapley algorithm only one side will behave according to his/her preferences – in the example given above only the side of men – while the other side will be better off, if they are not choosing always according to their preferences. The procedure is, therefore, not «strategy proof».

However, using the Gale–Shapley algorithm in situations where the criteria of choosing for one side can be controlled, e. g. in schools, then it is secured that the procedure is strategy-proof as well as stable. Moreover, Roth and his co-authors could show in diverse works, that the incentives and possibilities to manipulate the system in one's favour,favour are very low in practice under certain conditions [7; 16].

In numerous fieldfields, laboratory and computer studies it could be shown, that stability or instability in the sense of Gale and Shapley are in fact the decisive determinants for the success or failure of real matching markets [2; 22]. Instable allocation (matching) mechanisms lead typically to chaotic, inefficient and inacceptableunacceptable market clearing procedures and results characterized by very high costs of unsatisfactory allocations for the members.

An Application

One of many applications of the Gale–Shapley algorithm is the «New York City High School Match» [9]. In 2003 the manager of planning of the New York City Department of Education contacted Alvin Roth because the allocation of pupils to the high schools was problematic. New York City has seven high schools with about 500 course programmes. Every year more than 90 000 scholars apply for the different programmes. The course programmes have different criteria according to which they accept scholars. Some of the places were disposed by a lottery. For some programmes priority is given to scholars which live in the neighbourhood; for other programmes the final marks are relevant.

Up to 2003 the matching procedure was that the pupils could apply for up to five programmes. After the schools have made their decisions, the applicants of the respective school received a letter of acceptance or refusal or a place on a waiting list. Every pupil could – in case of receiving several acceptance letters – choose one as well as keep one place on the waiting list. All further acceptance letters and places on the waiting lists (if any) he had to refuse. Then the procedure went into two further rounds in which schools with now empty places could give these to pupils on the waiting list. In case of some pupils receiving no place these places were allocated manually. Besides, there existed the possibility of a law suit, which was used amply.

This procedure had several weaknesses: around 30 000 scholars did not receive a place in a programme they had chosen. Furthermore, the choice of the programmes was «strategically» – the scholars were advised by experts not to choose their preferred programmes, because it could happen that if refused there, the further programmes for which they also have shown interest were already overbooked.

Roth and his collaborators developed a new procedure on the basis of the Gale–Shapley algorithm. Here the pupils are allowed to mark up to twelve course programmes. In the procedure every pupil is then first allocated to his first choice. The schools (and course programmes) choose provisionally the pupils according to their criteria. In case a programme is overbooked, the refused pupils are allocated to their second choice, where it is checked whether these pupils fulfil the criteria better than those accepted provisionally in the first round, and so on. A software programme does this matching in the background so that the pupils are not aware of the procedure. Only when the allocation for all is finished, the pupils receive a letter with just a single offer. This procedure is successful. In the first year only 3 000 instead of 30 000 pupils as before did not receive a place in a programme that they have chosen.

Further Research Fields for Designing Matching Markets

Alvin Roth implemented similar programmes for the allocation of medical students to hospitals [11] and the allocation of scholars to schools in Boston [6]. He also developed a kidney exchange [8], where patients with kidney disease and having a donor who is not compatible with him/her could exchange this kidney with another donor-receiver pair with the same problem. Every new application raises however always new specific issues which must be taken into account in the market design. E. g. in the allocation of medical students (married) couples wanted to work in the same hospital. In Boston parents denied the possibility that pupils could exchange places between themselves. In the example of exchanging kidneys it is important to take into account that the surgeries of the donors are performed at the same time, because if a donor changes his mind he cannot be forced to do the donation. This reduces the size of the exchange ring.

It can be shown formally that under such practically relevant conditions sometimes the classical results of economics go lost, and one will be confronted as an economist with a multitude of non-constructive «impossibility results» [11]. It is the merit of Alvin Roth to have shown how the theory and other economic methods can be employed and developed to give nevertheless economically solid recommendations for market design. The work of Roth and Shapley related to matching markets have impressed on the science and brought up furthermore many interesting questions.

One branch of research is engaged with the question, why on these markets prices are not allowed, and what this implies for the optimal allocation procedure. Alvin Roth has written several papers on this theme. He defines the refusal of money as a constraint which has to be taken into account in market design [3]. New papers try to model the preferences of societies responsible for the ban of prices. One approach is the societal desire not to prejudice financially weak persons when choosing schools or allocating kidneys [23].

Another research branch starts with the observation that the Gale–Shapley algorithm takes into account only ordinal preferences, where schools are ranked. New approaches try to use also cardinal characteristics of preferences – school *A* is much better than school *B* while school *B* is only slightly better than school *C* [10]. This could for example be done by giving every pupil 100 points which then can be allocated to the schools to show the intensity of the individual preferences.

With matching markets also in the «practice of market design» there is still a lot to be done. Who once tried to find a place in the kindergardenkindergarten knows how inefficient and troublesome the standard matching procedures are. Also the allocation of pupils to schools, of students to universities or of students to seminar places can be investigated with the instruments of market design. In 2010 a European network was founded where scientists of economics, sociology and information systems meet to exchange their experience with such procedures [29].

The Economist as an Engineer

While until now the Nobel Prizes in Economics were given mainly for results in basic research, this year the «practice of market design» was explicitly honoured. The works of Roth and Shapley have impressed on this practice. They have shown how research and practice stimulate each other. Roth has reached into the real world to develop stable and efficient designs for the respective markets. Like an engineer he made use of different fields: game and auction theory as theoretical foundations, behavioural economics to better understand the market participants, laboratory experiments to test different scenarios, and information systems to implement the procedures. After the implementation the newly created markets were evaluated. The scientific results have guided his applications in practice,practice; the results in practice have stimulated his theoretical and experimental works [12]. This course of action defines the field of market designers, the economic engineer.

The field of market design goes far beyond matching markets. All centralized markets are open for the methods of market design. An interesting application for a market where prices play an important role are (online) auctions. In a series of papers by Alvin Roth and Axel Ockenfels [4; 5; 13]. it is shown that slightly different rules for ending an auction could have considerable impact on the gains of the seller, the offers of bidders and the selection of winners. eBay auctions with their fixed end lead to very late bidding with sometimes chaotic courses in the last seconds. Other auctions without a fixed end avoid strategic delays, however they can facilitate implicit agreements between bidders under certain conditions. New works on «economic engineering» with respect to eBay ask the question how trust can be built and reinforced in large, anonymous internet markets [19; 18].

The scientific theory of auctions is an important basis for market design. Also for work on this theme Nobel Prizes were awarded: 1996 to William Vickrey for his work on auction theory, 2007 to Leonid Hurwicz, Eric S. Maskin, and Roger B. Myerson for their work on mechanism design. The transformation of these theoretical results into practice forms a part of market design. Auctions are used worldwide in allocating telecommunication frequencies [26; 20], nowadays combinatorial auctions are used increasingly [26; 28]. In private shopping, in particular in bidding markets [25; 1], the methods of market design help optimizing the value chain, and also in public procurement the results of market design are used [24].

A new field of application of market design are A new field of application of market design is markets for energy. For the power exchange and for emission trading new rules must be centrally fixed. Or, as it is the case for capacity markets, the institution must be build first. Should also negative prices be possible in the energy market? How are the markets tied together? Is there a unique price or do bidders receive the offered price if they win the contest?

Market Design and Economic Policy

Markets are a powerful instrument. However, many markets need an active and careful design. Even small mistakes can lead to market failure. Economic engineers will be needed because the «invisible hand» alone cannot fix it often. Market design as a science and application is complementary to the school of ordo-economics. Both approaches deliver solutions for the treatment of a highly complex economic world. But while ordo-economics stresses the observance of general principles and from here deduces concrete recommendations, market design is occupied with theory-guided and empirically based transformation of incentive systems in view of the specific institutional complexities and behavioural phenomena of a given market.

For this, it is necessary to build up a scientific literature of the economic art of engineering. Until now too little is known how real markets are functioning in detail, and how men contribute to this with their frailties and limits. Neither in the ivory tower of economics nor in the experimental laboratory can it be investigated how real markets look like. The interplay of science and practice is the necessary condition to foster this field.

A next step is then to implement the results of market design into economic policy. The financial crisis has disclosed weaknesses of financial regulation which has not taken into due account the specific characteristics of financial markets. The turnaround in energy policy in Germany asks for a consistent frame for energy markets integrating the peculiarities of these markets, and leading to new innovative market designs. In competition policy new instruments for individual markets are devised like the (in Germany) planned institution for market transparency in the energy market and in the gasoline station market. In these cases one must take into account the specific characteristics of these individual markets and then incorporate adequately these characteristics in the regulation or competition policy.

The pioneering work by Alvin Roth and Lloyd Shapley shows how traditional basic research and market design stimulate each other in the support of men and markets. Opposite to many other research fields which were honoured with the Nobel Prize, in 2012 a field was honoured in which many questions are still open. There is a lot to expect from economic engineering in the future.

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