

CAN WE USE MATH TO DESIGN A BRIGHTER FUTURE?

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YOUNG REVIEWERS:



DIVYA
AGE: 13



LI
AGE: 11

Did you know that math can be used to help improve society? Well, believe it or not, it does so on a daily basis. Math not only helps us develop new technologies and engineering techniques, but also enables us to design modifications of our society that achieve desirable social goals—goals like reducing pollution and allocating resources to the people who value them the most. In this article, I will tell you about a branch of economics called mechanism design which helps economists do exactly that. Using mechanism design, we can reach important social goals that could not be attained without the modifications it points to. Keep reading to join me on a journey describing an economic theory that can help design a brighter future for us all.

Professor Maskin won the Nobel Prize in Economics in 2007, jointly with Profs. Leonid Hurwicz and Roger Myerson, for having laid the foundations of mechanism design theory.

ECONOMY

A system in which goods and services are created and distributed.

EXTERNALITIES

By-products of an economic activity that affect others but are not taken into account by the one pursuing the activity.

CAN WE DESIGN MODIFICATIONS TO THE ECONOMY?

A modern **economy** is a complex phenomenon that no one understands completely. When we think about the economy, we usually think of elements such as buyers and sellers, companies and consumers. These elements typically interact with one another pretty freely. That is, the interactions are largely not under the control of any supervisor such as the government. Nonetheless, using economic principles, laws, and regulations, we can often make modifications to the economy that improve people's lives.

For example, modification can help in an economy with important **externalities** [1]. An **externality** is the effect that a person or company has on others but that the person or company has no reason to take responsibility for. Take air pollution, for instance. If a steel manufacturing factory emits smoke into the air, that smoke will harm other people and damage the environment. But unless there is some sort of intervention, there is usually nothing stopping the manufacturer from continuing to pollute the air.

You might think that designing a modification to control air pollution is very easy—we can just prohibit everyone from releasing smoke into the air. But that would be “overkill.” Such a strict regulation would cause many businesses to shut down, and that would be bad for society. Alternatively, we can take a more sophisticated approach to reducing air pollution, while still allowing businesses to flourish. For example, we could require companies that emit smoke to pay a tax proportional to the amount of smoke they emit (Figure 1). Maybe for every metric ton of smoke emitted they must pay, say, \$100. Then, if a company emits 10 metric tons of smoke, they would have to pay \$1,000. The idea here is that the polluter should pay an amount equal to the damage they cause by emitting the smoke. This is a

Figure 1

Designing the modifications to deal with externalities. Air pollution is a common example of an externality. Polluters do not generally have an incentive to pollute less, unless the government intervenes in some way. One effective way is to tax polluters based on how much pollution they create. Illustration by: Iris Gat.



Figure 1

MECHANISM DESIGN

An economic theory that studies how to build institutions and procedures to achieve desired economic goals.

clever trick that gives businesspeople the incentive to do the right thing [2]. It ensures that they will take pollution into account when conducting their businesses. The trick is an idea from **mechanism design** [3–6], a fascinating part of economics that has been developing since the 1960's.

As you might expect, in certain situations it might be rather complicated to design the very best intervention to benefit society. Sometimes it may be hard to quantify the harm that a certain activity causes over time; at other times, many parties with different interests are involved, so an intervention needs to take account of all these parties; and often, additional issues such as fairness come into play. For example, to stop global warming, one potential solution is to tax countries according to how much carbon dioxide they release (since carbon dioxide in the air is responsible for the warming). But poor countries may have a harder time paying such taxes than rich countries, and a successful global-warming treaty must factor this in. Fortunately, even for complex problems, mechanism design can be very helpful.

MECHANISM DESIGN—MY LOVE AT FIRST SIGHT

I like to think of mechanism design as the “engineering” part of economics. Usually, in economics, we start by looking at existing economic institutions and try to understand what social outcomes they will lead to. However, in mechanism design, we reverse the direction and begin by deciding what social outcomes we would like to have and then ask how we might intervene in the economy by building institutions or procedures that will give rise to these outcomes (Figure 2). Mechanism design is often used to implement important social

Figure 2

Mechanism design. In mechanism design, we begin by deciding on our desired outcome (represented by the red target), such as a pollution-free environment. Then, we design and build the necessary institutions or procedures (represented by the red arrow) that will generate this outcome. Illustration by: Iris Gat.

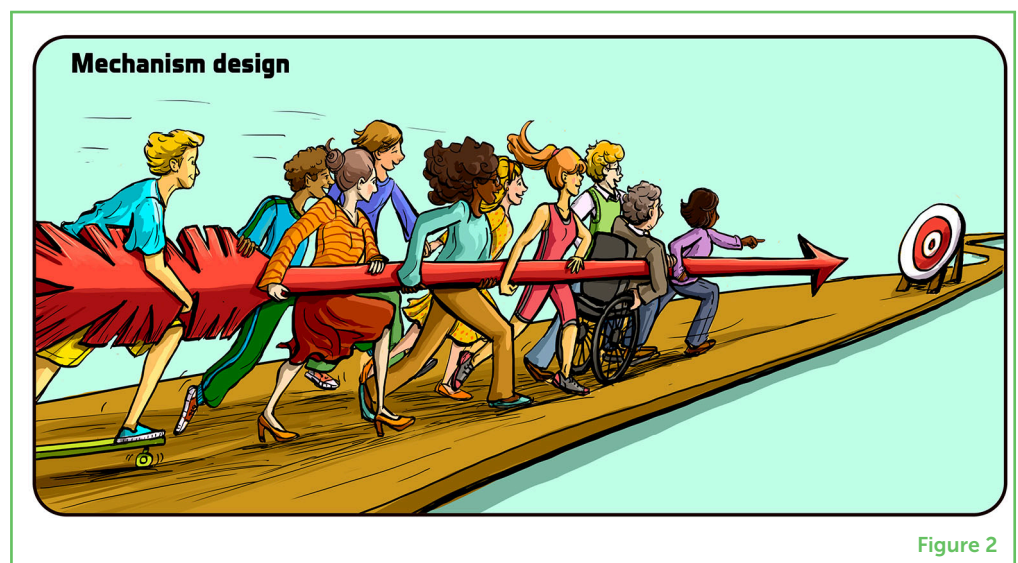


Figure 2

goals, such as protecting the environment and establishing fair and effective voting systems.

I first encountered mechanism design theory as an undergraduate at university, where I started out studying mathematics—a subject I had really liked since high school. In my last year at university, I took a course called Economics of Information, taught by Kenneth Arrow—a very well-known figure in the field who won the Nobel Prize in Economics in 1972. One of the topics that Arrow taught us was what would later be called mechanism design. It offered ways that math could be used to make improvements to society. This was a great revelation to me, as I did not know that math could be used this way, and it appealed to me. Like many young people, I felt drawn to do something good for society. Soon after I fell in love with mechanism design, I decided to earn a Ph.D. with Kenneth Arrow as my advisor. And my love for mechanism design is still alive today! More than 50 years later, I am still working in this field and trying leverage it for the benefit of society.

USING MECHANISM DESIGN: MY NOBEL DISCOVERY

To use mechanism design intelligently, we must first determine which social outcomes can and cannot be achieved. There is a part of mechanism design called **implementation theory** [7] that helps us answer this question. Implementation theory allows us to characterize, in mathematical terms, the achievable social goals—the goals that can be reached by some procedure.

For example, imagine a situation in which society has four possible energy sources—natural gas, oil, solar energy, and nuclear energy—to choose from and must select just one of them. Each citizen has a personal ranking of the four options. We might ask: Can society design a procedure to reach the goal of selecting an energy source all citizens will be reasonably happy with—one that makes a good compromise between the rankings of different citizens?

My research on implementation theory implies that the answer to this question is yes provided that the rule for determining the compromise satisfies a condition called **monotonicity** [8]. Roughly speaking, monotonicity means that if, say, solar energy makes a good compromise given a particular configuration of citizens' rankings and we now look at a different configuration in which citizens like solar no less than before (so that if, for example, a citizen previously ranked solar above oil, she continues to rank solar above oil), then solar must continue to make a good compromise for the new configuration.

This discovery about monotonicity was the work singled out by the Prize committee when they awarded me the 2007 Nobel

IMPLEMENTATION THEORY

A subfield of mechanism design that studies which goals are achievable, and which are not.

MONOTONICITY

A key requirement for a goal to be achievable. It demands that if a certain outcome is the goal in one situation and is not ranked lower by anyone in a different situation, then it must also be the goal in the second situation as well.

Prize in Economics, jointly with my colleagues Leonid Hurwicz and Roger Myerson.

AN EXAMPLE OF MECHANISM DESIGN IN ACTION

One important feature of mechanism design is that it allows us to implement goals in situations where we initially lack crucial information. Here is an example: Suppose you have a valuable item that you cannot use yourself and so want one of your friends to have. It can be anything worthwhile—maybe an old guitar, a rare book, or a concert ticket. Since the item is valuable, you want the friend who values it the most to get it. The problem is that you do not *know* how much each friend values the item. What can you do?

You might try setting up a bidding competition between your friends. Each friend makes a bid (an amount of money she is willing to pay for the item) and the winner is the one with the highest bid. However, if the winner actually pays her bid, she will have an incentive to underbid—to bid less than her value for the item. To see this, imagine the value the friend places on the item is \$10. If she bids \$10 and wins, then she will be getting something worth \$10 but paying \$10—so, her net gain is \$0. That is, the only chance she has for a positive payoff is to bid less than \$10. But if all your friends are bidding less than their actual values, there is no guarantee that the one who values the item the most will have the highest bid. In other words, the wrong bidder might win.

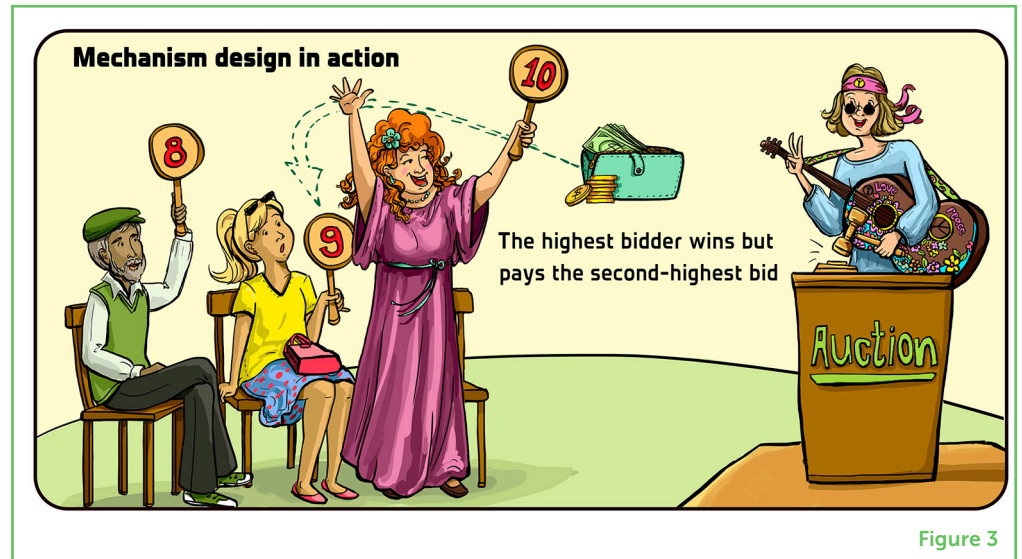
Mechanism design suggests how to modify the competition to solve this problem. The winner of the competition will still be the person who bids highest, but you tell your friends that the winner will only pay the second *highest* bid that was offered [9]. For instance, if the highest bid was \$10 and the second highest was \$9, then the person who offered \$10 gets the item for \$9 (Figure 3). This simple yet clever procedure ensures that each bidder will bid exactly the amount that the item is worth to her. This is because no one will be motivated to underbid any longer since they do not pay their bids anyway and so do not reduce their payments by underbidding. Moreover, if they do underbid, they could well-regret doing so. If the item is worth \$10 to me and I bid only \$8, I will lose to someone who offers \$9. And that will be too bad for me because if I had bid my true value, I would have won and earned a net payoff of \$1 ($\$10 - \9).

Since all your friends will bid their actual values in this modified mechanism, the winner will indeed be the one with the highest value—and so your problem is solved. This bidding procedure—or variations of it—is often used in real-world situations, such as when the government wants to sell radio spectrum to telecom companies.

This is just one example of how mechanism design helps designers (e.g., governments or organizations) to achieve their goals, even when

Figure 3

Mechanism design in action. A bidding procedure that ensures each bidder bids the exact amount that the item is actually worth to them. In this procedure, the highest bidder is the winner, but that person only pays the amount of the second-highest bid. Illustration by: Iris Gat.



they lack important information (in the example, you did not know your friends' values). As I mentioned earlier, mechanism design can also be used for creating international agreements between countries (to reduce greenhouse gas emissions, for example), and for calculating the right taxes on smoke pollution. Over the years, mechanism design has been very successful, and I am certain that it will continue to be helpful for years to come.

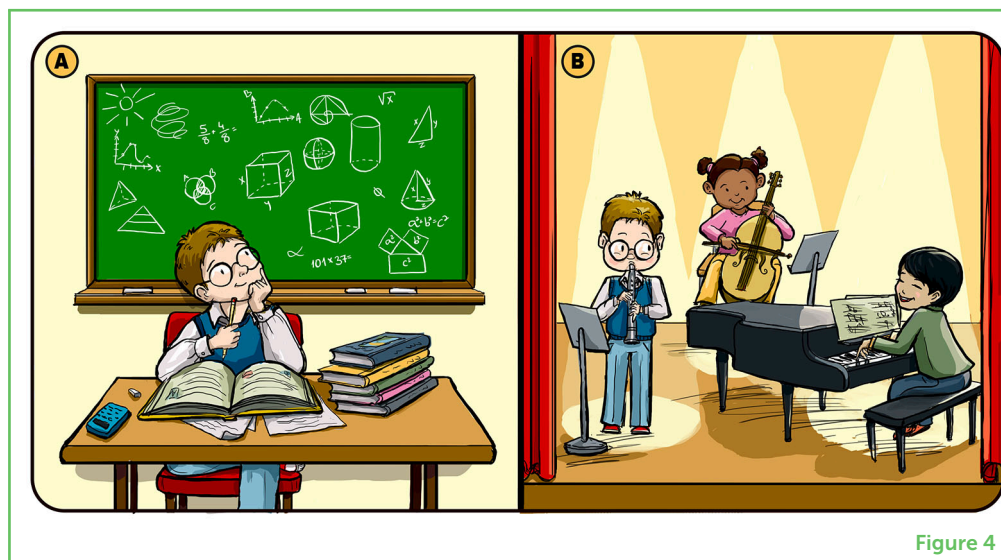
RECOMMENDATIONS FOR YOUNG MINDS

What you do in life is very much a personal choice. People have different tastes and preferences about how they want to spend their lives, and many possible choices are valid. Based on my personal experience, however, I want to make a pitch for scientific research as a career. There are very few other jobs in which you will have so much control over what you are doing. In scientific research, you get to decide on the questions that you want to answer (Figure 4A). No one tells you what you should study—you get to choose the topic. This gives you a great sense of freedom and independence that is rarely found in other lines of work.

Additionally, human beings are curious creatures by nature, and they want to know the answers to lots of questions. Currently, science is one of the best means we have for satisfying curiosity. Sometimes science can be frustrating because you can work for a long time and not feel as though you are getting anywhere. So, you have to be patient. But personally, I can think of few occasions in my life when I was more excited or gratified than when I answered a scientific question I had been struggling with for a while. It is a wonderful thrill, and if that kind of reward appeals to you, I definitely recommend a career in research.

Figure 4

Recommendations for Young Minds. **(A)** For me, one of the biggest thrills in life is answering a scientific question I have been struggling with for a while. If you share this thrill, I advise you to pursue a career in research. **(B)** If you do choose research as your career, I recommend that you find a hobby or activity to enjoy in your leisure time—one that will balance your scientific work by providing an emotional and social outlet. Illustration by: Iris Gat.



If you do choose research as your career, I recommend finding an activity to balance your work. For me, this is playing music (Figure 4B). I play the clarinet, and I have a trio with a cellist and a pianist. Music is a wonderful complement to my professional life. Though doing research is a lot of fun, it is often a somewhat lonely activity and one in which you cannot readily express your feelings. In contrast, making music is highly social and there is a lot of opportunity to put your emotions into the music, so it is a very good outlet. If you are not attracted to music, you can choose some other activity that allows you to freely express yourself and connect with others in beautiful ways. This, together with your work, will give you some balance in life.

ACKNOWLEDGMENTS

I wish to thank [Noa Segev](#) for conducting the interview which served as the basis for this paper, and for co-authoring the paper, and [Iris Gat](#) for providing the figures.

ADDITIONAL MATERIALS

[Mechanism design theory—Eric Maskin—YouTube.](#)

[Games and how math can help us win them—Frontiers for Young Minds.](#)

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SUBMITTED: 29 November 2022; **ACCEPTED:** 26 June 2023;

PUBLISHED ONLINE: 29 January 2024.

EDITOR: Idan Segev, Hebrew University of Jerusalem, Israel

SCIENCE MENTORS: Jiayuan Lin and Sriram Srinivasan

CITATION: Maskin E (2024) Can We Use Math to Design a Brighter Future? *Front. Young Minds* 11:1111437. doi: 10.3389/frym.2023.1111437

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YOUNG REVIEWERS

DIVYA, AGE: 13

I find the intersection of science and creative writing fascinating. My other passions include classical vocal music and learning languages. In my free time, I enjoy reading, as well as creating and solving puzzles.

LI, AGE: 11

My name is Li. I love reading books, especially mysteries. I am very interested in math, science, and history. I enjoy arts, writing, and swimming. During my spare time, I also play flute and guzheng.



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Prof. Eric Maskin is an American economist and mathematician. He is the Adams University Professor and a professor of economics and mathematics at Harvard University (United States) and a Chief Research Fellow at the Higher School of Economics (Russia). Prof. Maskin earned his A.B. in mathematics and his Ph.D. in applied mathematics at Harvard University. During his Ph.D., Prof. Maskin took several courses in economics and met Roger Myerson, his co-laureate. Prof. Maskin's research dealt with finding the conditions under which a mathematical function called the social welfare function is solvable. After his Ph.D., Prof. Maskin served as a postdoctoral fellow at Jesus College, Cambridge University (England), where he studied the circumstance under which a mechanism to implement a given social goal could be designed, and he developed what is now called Maskin monotonicity. In 1977, Prof. Maskin joined the Massachusetts Institute of Technology (United States) as a faculty member. Between 1985 and 2000, Prof. Maskin was a faculty member at Harvard University, where he rejoined in 2012 after serving as a visiting professor in the Institute for Advanced Study (New Jersey, United States) between 2000 and 2011. In 2007, Prof. Maskin was awarded the Nobel Prize in Economics, jointly with Leonid Hurwicz and Roger Myerson, for work on what is called mechanism design theory, a theory that attempts to maximize gains for economical players within economic markets. *emaskin@fas.harvard.edu