



## CAN WE USE MATH TO DESIGN A BRIGHTER FUTURE?

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**Abstract:** *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.*

### **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. 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. 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 clever trick that gives businesspeople the incentive to do the right thing. It ensures that they will take pollution into account when conducting their businesses. The trick is an idea from mechanism design, 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

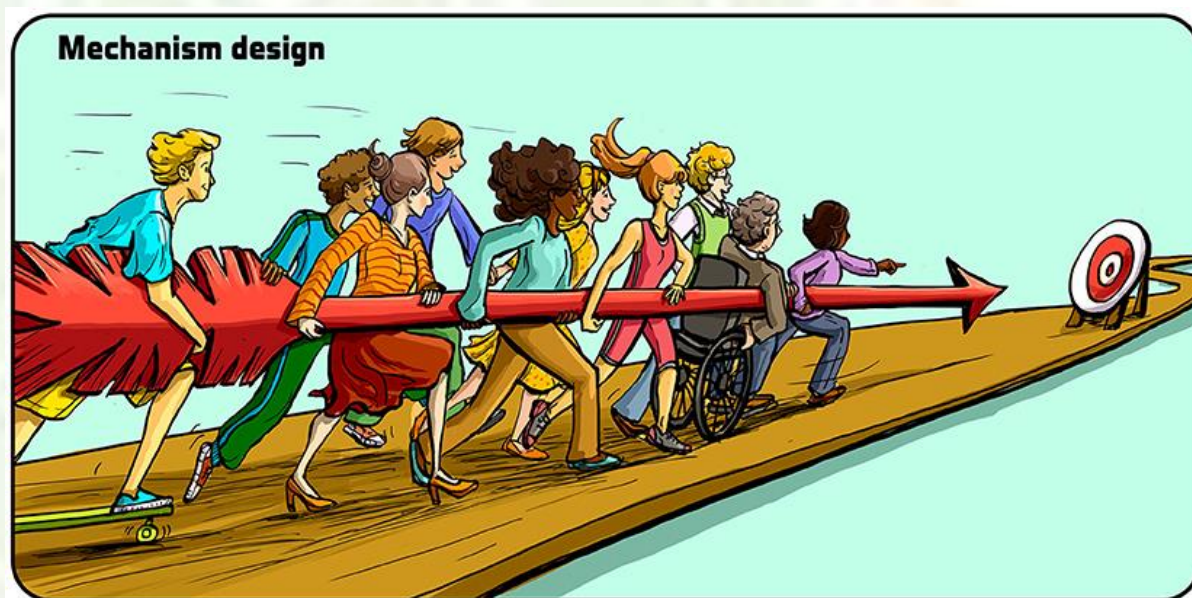




these parties; and often, additional issues such as fairness come into play. For example, to stop global warming, one potential solution is to tax countries according to how much carbon dioxide they release (since carbon dioxide in the air is responsible for the warming). But poor countries may have 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. Mechanism design is often used to implement important social 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 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. 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.

## **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. 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. 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 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.

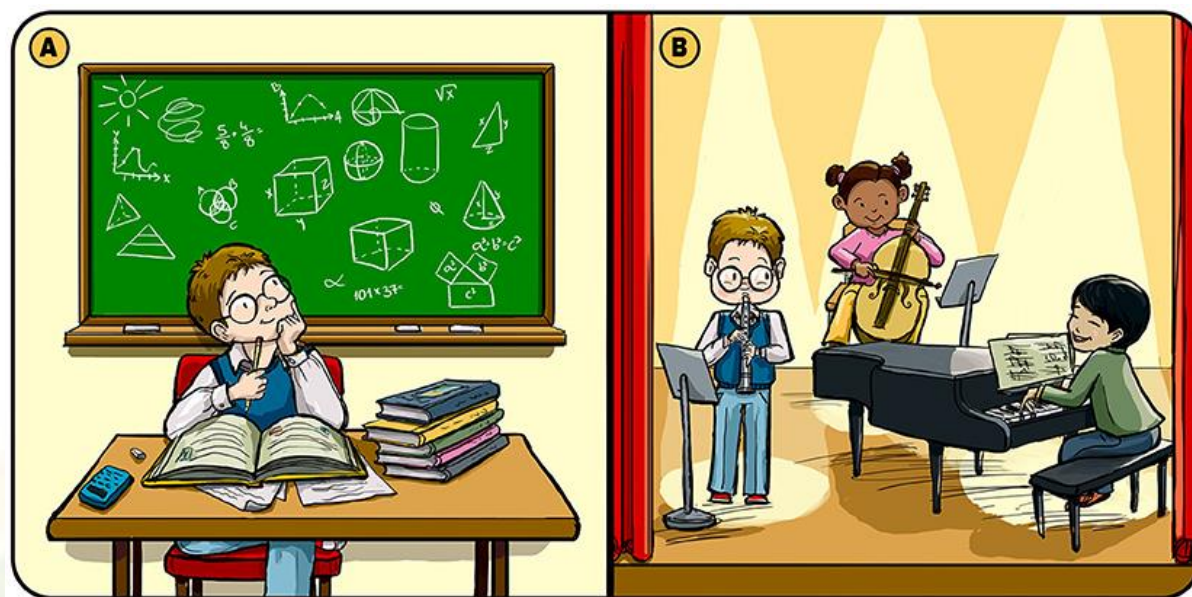
## Recommendations for young minds

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. 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.

If you do choose research as your career, I recommend finding an activity to balance your work. For me, this is playing music. 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.



## Glossary

1. Economy: ↑ A system in which goods and services are created and distributed.
2. Externalities: ↑ By-products of an economic activity that affect others but are not taken into account by the one pursuing the activity.
3. Mechanism Design: ↑ An economic theory that studies how to build institutions and procedures to achieve desired economic goals.
4. Implementation Theory: ↑ A subfield of mechanism design that studies which goals are achievable, and which are not.
5. 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.

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