Applications to Economics and Finance: Challenges, Results, and How Systems, Man, and Cybernetics (SMC) Research Can Help

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Economies and finance are important. New inventions, new discoveries, new designs make our life better and better. From this viewpoint, scientists and engineers are the ones who we should thank for the great technological progress. Newton discovered laws of motion and laws of gravity – and now we use them to launch spaceships to Moon and to other planets. Edison invented an efficient light source – and we all now enjoy light. But for an invention to be practically used, there needs to be an economic incentive. Without economic support, ideas remain ideas. For example, steam engine was discovered centuries before James Watt, by Heron from ancient Alexandria. But in the ancient world, when slave work was cheap, there was no incentive to use steam in practice. Heron's machine was only used in rituals – to automatically open temple doors. Similarly, contrary to the widespread opinion, the Mayans *did* discover the wheel. They use wheels in toys for kids. However, they never used wheels for transportation – because there was no benefit in using it.

Not only bad economics stalls the progress and prevents our level of living to grow. Bad economics – e.g., during severe economic crises – actually lowers our level of living.

It is therefore important to control economies and finances. Most crises do not happen because of someone's bad behavior or bad intentions. They appear naturally – because the corresponding complex systems are not always stable. When there is a shortage of some goods, it is beneficial to produce them. So, many people start producing them – and this causes overproduction. The supply exceeds demand, prices fall, companies go bankrupt, resources are

wasted. In the US, everyone saw pictures in history books of milk poured away during the Great Depression. To avoid such disasters, we need to control the economy. And for that, we need to be able to predict how different economic interferences will affect the economy.

At first glance, this sounds like a usual engineering control problem. The need for control and prediction is ubiquitous in engineering. For example, we need to control a spaceship to make sure that it reaches its destination. And for this purpose, we need to be able to predict how different controls will affect the spaceship's trajectory. This similarity between economic and engineering problems was noticed by Norbert Wiener, the founder of *cybernetics*. Cybernetics is, by definition, a study of processes common in engineering systems and in living systems.

In general, this similarity has led to many interesting ideas and developments, made cybernetics an effective tool. In 1960s, many companies and many governments effectively used physics- and engineering-based numerical methods to boost productivity.

Challenges emerged. However, in the 1970s, serious problems emerged. Many companies and countries that used these methods had problems. Companies went bankrupt, economies tanked. For example, Chilean economy – that was, under Allende, run by cyberneticians – experienced hyperinflation. Parodying Freud, traditional economists started to derogatorily call numerical methods "physics envy".

But why methods that work so well in engineering did not work as well in economics? Our knowledge is never perfect. All models are approximate. It turns out that economic models are much less accurate than engineering ones. This larger inaccuracy affects the results.

There is also a more fundamental reason. In engineering, the main objective is to make the system run. Optimization is often an icing on a cake. We want an airplane to fly safely. If it is the best in saving fuel, great, but this is rarely achieved. In contrast, economies do not need our control to run, they run by themselves. Optimization is the whole objective here. And optimization based on an approximate model can lead to a disaster.

For example, when a new need appears, the profit increases with the production volume. In the first approximation, every smooth depebdence can be well approximated by a linear function. For a linear dependence, optimization means maximizing the production. And this is exactly what causes overproduction and crises.

A more complex example is the 2018 financial crisis – that was largely caused by such a problem. Stock prices fluctuate. These fluctuations are caused by many independent small factors. According to the Central Limit Theorem, the probability distribution of such summary variables is close to normal. For a normal distribution, deviations larger than 6σ are practically impossible. So, investors assumed that larger decreases are not possible. And when such large decrease happened, there was no cushion, the stock prices decreases by half.

But why are economic models less accurate than engineering and physics ones. There are several reasons for this inaccuracy. To understand these reasons, let us recall where our knowledge of engineering systems come from. Just like all knowledge in natural science, it comes from the following four sources:

1. *Observations and measurements:* We can gain knowledge by observing the system's behavior. Most engineering systems are deterministic. So, if a similar situation happens next time, the system's behavior is usually the same.

2. We can *experiment with the system as a whole* – as a black box. We can experiment with most actual engineering systems – thus gaining additional knowledge.

3. We can also *experiment with parts of the system.* Engineering systems consist of simple parts. We can separate each part, study its behavior, understand how it behaves. By combining models of the parts, we can get models of the whole system. (Often, such a detailed model is too complex to use. In such cases, we use *systems approach* to come up with a good approximate model. A good example is system of systems technique.)

4. *Using first principles:* We can also describe the parts' behavior from first principles – by using known basic laws of physics and mechanics.

In contrast:

1. Economic systems are not as deterministic as the engineering ones. A faraway event – e.g., a devastating flood in the other part of the world – does not affect the performance of an airplane. However, all such events may (and do) affect the economy. In other situations, these events are usually different. As a result, the system's behavior may be different.

2. We cannot seriously experiment with economics. No big harm is done when a newly designed unmanned spaceship collapses. This is a normal process. But an economy collapse would be a disaster.

3. Economic systems do consist of parts: these parts are humans. We *can* observe human economic decisions. However, it is not possible to separate a human decision maker from its environment. Even simple win-an-amount-lose-an-amount experiments depend, e.g., on the person's current and expected wealth. So, it is difficult to experimentally analyze human behavior.

4. From-first-principles approach is also not working well in economics. Traditional economic models were based on the seemingly natural assumption that humans are optimizers. However, this assumption is an approximation. Our optimizing abilities are limited. The Nobelist Kahnemann and other call this " bounded rationality". Because of our limited abilities,

we often do not follow supposedly optimal predictions and advices. This was noticed long ago. For example, in the 1970s, Janusz Kacprzyk worked at the International Center in Laxenburg, Austria, on optimizing agriculture. They spent a lot of time optimizing, but most farmers rejected their original recommendations. Researchers had to modify their recommendations by taking the farmers' opinions into account. There is a whole area of economics that takes into account bounded rationality. It is called *behavioral economics*.

There is also an important additional reason why economic models are less accurate.

- For an engineering system, once we found out how it behaves, we can expect the same behavior in the future.
- In contract, in economics, knowing the laws changes the behavior. For example, if we become able to better predict how stock prices change, the stock prices immediately change. For example, prices of stock that is predict to rise go up, and vice versa.

Since models are approximate, to make good decisions, we need to know how accurate is the model. Engineering systems usually do not change with time. Unless we make changes, the future inaccuracies will be similar. This is a perfect situation for traditional statistical techniques. In contrast, economic systems are dynamic, they always change. The inaccuracies also change, we cannot describe them by more traditional statistical techniques such as p-values. We need techniques such as:

- imprecise probabilities – that take into account that we do not know exact values of the probabilities,
- Bayesian techniques – that take into account precisely described prior knowledge,
- fuzzy techniques – that take into account prior knowledge described in imprecise natural-language terms, etc.

It is also important to explicitly take dynamics into account, because some seemingly random behaviors actually come deterministic dynamics. We have shown, on a simple example, that a simple supply-and-demand behavior can lead to periodic boom-bust behavior. Similarly, a more complex deterministic behavior can look random. This is called *chaotic systems* – and they have been successfully used in economics.

What can we do about it. The above challenges naturally necessitate using all three directions of the SMC Society research:

- Since we cannot form a model of an economic system by analyzing its parts, we need to more actively use *systems approach* – designed to study systems as whole.

- Since a lot of problems come form involvement of humans, we need to better take into account *human* aspects.
- Finally, we need to use the general idea of *cybernetics* and utilize solutions of similar problems in other areas.

And, of course, all these there aspects need to be combined.

All there aspects are already actively pursued in econometrics. A special emphasis is placed on the cybernetics approach. This approach is theoretically justified by the notion of NP-completeness. According to this notion, all most complex problems – called *NP-complete* – are equivalent in the following sense: each instance of one problem can be feasibly reduced to an instance of another such problem. This is not just a theoretical result. For example, SAT-solvers are actively used to solve all kinds of planning problems. They were even used by NASA in planning and controlling missions to distant planets. In econometrics, researchers have successfully used such reduction to problems from engineering (e.g., optimal transport) and physics (thermodynamics, quantum physics, etc. – this research direction is called *econophysics*). In particular, symmetry techniques – one of the main techniques of modern physics – have been used to explain empirical dependencies and to come up with more accurate models of the corresponding behavior.

What we do and how we can collaborate. All these topics are actively researched at the Ho Chi Minh City University of Banking and at the Chiang Mai University. Every year, these universities hold annual back-to-back international conferences on econometrics and finances that bring in renowned researchers – all the way to two Nobel Prize winners. Selected papers from these conferences have been published by Springer as edited books. Each year, these conference – and the resulting books – have a different focus. We had volumes focusing on behavioral economics, on AI and machine learning techniques, on optimal transport techniques, on quantum econometrics, and on many other topics. The Ho Chi Minh City University of Banking also publishes an international journal called *Asian Journal of Economics and Banking* (AJEB).

It will be great to have more people from SMC community to participate in our conferences and to submit their related paper to our journal. We will also try to better advertise SMC events and journal among our econometrics community.

This does not have to be a one-way street, consisting of only applying SMC techniques to econometrics. While traditional engineering systems were not able to learn, more and more engineering systems are now endowed with AI-based ability to learn. Engineering systems thus become dynamically changing, based often on resource-limited (thus imperfect) optimization. So, in predicting and controlling the behavior of such systems, we start encountering the same problems as with economic systems. It is therefore reasonable to expect that techniques developed in econometrics may help future AI-based engineering systems.