The Impact of Advanced Computing on Theoretical Economics Research

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction

Throughout human history, research has always been influenced by the technologies available. In 1798, English scientist Henry Cavendish made one of the first attempts ever to measure the strength of gravity. He used a simple device called a torsion balance, which is two masses at opposite ends of a beam. Over two hundred years later, physics research makes use of the Large Hadron Collider, space telescopes, and massive fusion reactors. Technological progress gives researchers new tools to perform research with, changing the nature of the research and ultimately influencing the results of that research.

This should matter to everyone because the results of research influence society broadly. Research results are used not just in creating new technologies or formulating complex theories that explain our reality but are often used in crucial decision making from governments, private corporations, academic institutions, and individuals. An example of a field where this is clearly true is theoretical economics. For example, the Federal Reserve, which ultimately sets America's monetary policy through the manipulation of interest rates and currency, impacting the financial situation of millions of citizens, weighs the implications of many theories (like Keynesian vs Classical economics) to make its decisions. Professional investors pick and choose which stocks to invest in, ultimately influencing the composition of the US financial system, based on financial theories. It's clear that the results of theoretical economics research have a massive impact on society.

In the last 50 years, arguably the most significant and impactful technological development in the world has been computers. The total computing power available to humanity has grown exponentially in this time period, and many different disciplines have undoubtedly been affected by this technology. This paper will attempt to analyze the impact of computing on theoretical economics research. More specifically, it will attempt to answer the question "*To what extent have better computing capabilities impacted the development and perception of economic and financial theories?*"

Background & Context

The total computational power available to humanity has drastically increased due to a combination of the increase of computers' popularity and technological advancements that have created more powerful chips. The result is that nearly every aspect of human society, especially in developed countries like the United States, has experienced either a change or a total paradigm shift from computation. This is the case for research done in the "hard sciences", like biology, chemistry, and physics, where increasingly computers are being used to perform simulations or process complex data. For example, biologists have used computer simulations to show that the human eye could have developed through evolution, providing evidence to validate a theory (Backhouse, 2017).

However, according to some literature, the effect of computation on research for social sciences, like psychology, sociology, and economics, has been relatively muted (Lazer et al, 2020). For economics specifically, research may be loosely broken up into two fields: applied economics and theoretical economics (Backhouse, 2017). Applied economics is generally the study of real-world economics and is heavily focused on data and statistics, so the application of computers has had a significant impact on the field. An example of this is an NBER journal covering the impacts of machine learning on applied economics (Athey, 2019). Theoretical economics, on the other hand, is concerned with the development and analysis of theoretical models, which are often generalized equations or charts to describe economic situations.

Literature Review

The literature surrounding the impact of computing on economics is widespread, but research focusing in on theoretical economics research is less common. In general, the literary consensus seems to be that the adoption of computation in a significant capacity to theoretical economics has been slow but is starting to progress.

An example of this is the "Computation Economics" chapter of The Oxford Handbook of Philosophy of Economics (Humphreys, 2009). In this chapter, Humphreys states "Computational economics is a relatively new research technique…," despite the book being published in 2009 and computers starting to become popular in the 70s and 80s. Judd (1997), argues that many theoretical economics researchers have expressed opposition towards the use of computation and that, as of 1997, a debate had been ongoing in the community as to the proper role of computers in research. Judd also argues that economics lags other fields, like hard sciences, in adoption of computers. Backhouse (2017) argues that computers have transformed applied economics work more significantly than it has transformed theoretical economics work, which matches Judd's argument of computers being more easily applied to quantitative analysis fields (like hard sciences and applied economics) than qualitative analysis fields (like theoretical economics). Other sources argue that economics is becoming "increasingly computerized," but that economists still tend to shun true simulation models (Lehtinen, 2007). These sources seem to reach a consensus in concluding that theoretical economics research has not drastically changed due to computing.

However, there are areas in which further computational upgrades and more focus on the intersection between economics and computing has made a difference. For example, MIT professor Constantinos Daskalakis has approached the question of what computer science can teach economics, namely the calculation of Nash equilibria in game theory (a "solution" to a game theory problem in which no players can benefit from changing their strategies), and whether calculating these equilibria for markets can perfectly describe behavior (Hardesty, 2009). Daskalakis reached the conclusion that "… for some games, the Nash equilibrium is so hard to calculate that all the computers in the world couldn't find it in the lifetime of the universe." Thus, the existence of computers helped us find out that a particular theoretical economics problem is unsolvable, which advances the field. However, in this case, it wasn't the increase in computing power that helped to reach this conclusion, but rather approaching the problem from the perspective of a computer scientist. Recently, there has finally been a pivot to the use of computation in narrow fields of theoretical economics, like agent-based modeling (Tesfatsion, 2023).

My paper will seek to understand the true impact of computational power on theoretical economics by analyzing how theoretical economics papers have changed over the decades because of computation. Then, this evidence will be used to construct a holistic, STS understanding of the intersection of computers and economics.

Theory

This topic represents a mutual shaping between society and technology. As established in the introduction, the technology available to researchers influences the type of research they do and ultimately the results they obtain. The knowledge gained from this research is then applied both to influence various aspects of society and to further develop technologies. For theoretical economics specifically, the research results impact the incentives and functioning of the economy through monetary policy and decision making. The state of the economy then influences the development of technology by impacting the allocation of resources to R&D, technology companies, or academic institutions. In summary, technology influences society (specifically the economy and financial institutions) through the mechanism of research because technology available impacts the type of research that can be done (which is then applied to policy and decision making in society), and society then impacts technology available by the allocation of resources towards technological development. Thus, this mutual shaping is a complex sociotechnical relationship that has significant implications on both technology and society.

Methods

The evidence that I want to collect is the top economics theory research papers over the last 50 years and how significant the contribution of computing is to those papers. By comparing how significant a contribution computing made on economics at different time periods, I can draw conclusions about how the field overall was impacted by computing. Ultimately, it's not extremely important to get the *exact* top research papers in each decade; I simply want a snapshot of what the influential research looked like at the time. Thus, if the papers are clearly influential (cited many times) and from the correct time period, as well as being a high-quality scholarly source, they will be applicable for my research. The most important thing is that my selection should be entirely random with respect to the impact of computing on the paper. I should have no prior knowledge of the impact of computing on the paper to prevent myself from being biased regarding which papers are chosen.

To get this evidence, I used Google Scholar to find scholarly sources. While Google Scholar is generally not the best search engine for research, it is easy to use and will give satisfactory results for what I want, especially after I personally verify the results. The search term “economics theory” will be used since this should generally give results for the field I want, and I can then narrow down the search afterwards. Specifically, since I want the “top” research papers in each time period, I will use the most cited papers. I will collect two papers from each decade since 1970, so I will have the top two most cited papers from 1970-1979, the top two from 1980-1989, etc until 2010-2019. Because Google Scholar natively doesn’t support sorting by citations, I will use a tool named "sortgs," found on Github (https://github.com/WittmannF/sort-google-scholar), which will sort my search by total citations. Google Scholar returns scholarly sources so I can verify the authenticity of my evidence, and I will further verify the authenticity by ensuring the sources are from reputable journals. Sorting by high citation counts should help verify the credibility and representativeness of the evidence.

Some processing will have to be done upon getting the sortgs results. First, I will filter out any sources that are books as opposed to journal papers to reduce the scope of my research. Second, I will have to go paper by paper in the top results to ensure I’m using actual economics theory papers instead of papers from other disciplines that got included in the results. Finally, the papers collected will be analyzed. For each of them I will read the important sections and skim through the rest to A) get an understanding of the overall topic of the paper so I can analyze how important computing is and B) look for specific mentions of computing in the paper. These two pieces of information will help answer the question of how important computing is for the research done.

Results

The first paper analyzed from the 70s was Charnes et al (1978). This paper presents a novel theoretical economic model to evaluate the efficiency of decision-making units, especially in public and other nonprofit sectors. It uses complex mathematical proofs to produce equations for these efficiency numbers. Computation is used heavily within the paper, as some of the linear and nonlinear programming problems required the use of computers to solve and the complexity of the data likely required computers. For example, the paper mentions "These [efficiency] values, however, are obtainable within the computational process..." (439), which clearly indicates that computational process is required to compute some of the equations. They also mention in the conclusion that they have provided "...both models and computational procedures." Some of the models and equations used in the paper are complex enough that advanced computation is clearly required.

The next 70s paper analyzed was Fama (1970). This paper is a mix between theory and applied work, where Fama analyzes the efficiency of stock markets through the lens of various financial theories by comparing research that tests these theories against stock market data. Computing is used in this analysis but primarily for empirical work to confirm the theories, specifically by statistically analyzing stock market prices. The quote "After Bachelier, research on the behavior of security prices lagged until the coming of the computer." (389) suggests that increasing computational power had a significant impact on the development of certain economic theories. This example shows how the transformation of applied work due to computing can indirectly also transform theoretical work, as applied work can provide the empirical support needed to validate economic theories. Thus, computing may have a positive impact on the development of theoretical economics research by positively impacting applied economics research (allowing for better statistical analysis) which can be used as evidence to validate theoretical models.

The first 80s paper analyzed was Wernerfelt (1984). This paper presents a paradigm shift to analyzing the advantages that firms have over other firms. The paper is purely theoretical and introduces a new theoretical framework which has since been used extensively. It makes no mention of computers nor does any of the analysis require the use of any significant computation.

The second 80s paper analyzed was Lucas (1988). This paper analyzes different models for growth theory to construct a high-quality neoclassical model of growth that could explain the varying development levels and economic growth rates of different countries around the world. This paper is primarily theoretical as it just explores models and their implications and uses a lot of math and formulas. It does use some real-world data to find basic solutions to models, which likely was done using computers, but apart from this, there is little evidence that computers were significantly used in the analysis. One interesting quote is when Lucas mentions "I prefer to use the term 'theory' ... to refer to an explicit dynamic system, something that can be put on a computer and run" (5). This contrasts with some of the conclusions from the literature review, where some authors think many economists are shunning computer and simulation models.

The first 90s paper analyzed was Grant (1996). This paper attempts to further develop a "knowledge-based" theory of the firm, which views the role of a firm as organizing and coordinating specialist knowledge to produce goods and services. There is no mention of computers in the paper and no indication that computers would have needed to be used for any purpose, as the paper is purely a conceptual analysis and compiles existing qualitative research.

The second 90s paper analyzed was Donaldson & Preston (1995). This paper analyzes the "stakeholder" view of the firm, in which firms shouldn't simply prioritize profit to shareholders but should consider all groups that have a stake in a firm's activities. It concludes that the normative argument (a firm's ethical obligation) is the most fundamental to this theory. The paper is again purely conceptual and is based on a review of existing research and legal frameworks, so computers have no impact on the analysis conducted.

The first paper reviewed from the 2000s was Etzkowitz & Leydesdorff (2000). This paper introduces the "Triple Helix" model, which emphasizes the role of universities in innovation systems, alongside governments and industries. There is a little contribution of computation to this paper: Etzkowitz mentions that "In a contribution entitled ‘The Triple Helix: An Evolutionary Model of Innovations,’ Loet Leydesdorff uses simulations to show how a 'lock-in' can be enhanced using a co-evolution like the one between regions and technologies" (27). The computer simulations here were used to analyze how innovation networks can evolve over time and explore different scenarios. This is another example of researchers using computer simulations to validate or present a theoretical economic model. However, outside of this small section of the paper, the theoretical analysis is still largely conceptual and doesn't make much use of computers.

The second paper from the 00s was Collier (2004). This paper looks at historical data on civil wars and analyzes whether political grievances or economic opportunity are stronger motivators of civil war. The authors use a robust econometric model to find that economic factors have considerably more explanatory power for the outbreak of civil wars than political repression, ethnic/religious differences, inequality, etc. The use of computers in this analysis was extensive, with the authors producing logistic regression models and handling large datasets. They also did significant statistical testing and robustness checking which required re-running models dozens or hundreds of times, which would have been extremely time-consuming or near impossible on a much weaker computer.

The first 2010s paper analyzed was Ostrom (2010). This paper challenges the notion that the "market" and the "state" are the only systems for efficiently managing public goods and common-pool resources, and instead explores institutions at multiple levels of human interaction to find efficient solutions. The paper is extraordinarily well-researched and multi-disciplinary but the impact of advanced computational power is not extremely apparent. Computers were likely used in the analysis of many meta studies and empirical work, but there's no evidence anything majorly complex was done. However, one interesting point of note is in her explanation of how game theory could be used in her framework: "...colleagues have been able to use formal game theory models consistent with the IAD framework to analyze simplified but interesting combinations of theoretical variables and derive testable conclusions from them ... as well as agent-based models" (647). This is interesting because game theory and agent-based modeling are the two fields of theoretical economics most agreed upon to be the most transformed by computation (Backhouse, 2017).

The second paper from the 2010s is Connelly et al (2010). This paper attempts to build a comprehensive understanding of signaling theory in management. The contribution of the paper is its conceptual work, so computers are not used in any significant capacity.

Analysis

Overall, it appears that the use of advanced computation in theoretical economics research is not particularly common. Half of the papers analyzed did not mention or use computers at all, and there is no clear correlation with the time period these papers were released in. Figure 1 shows a simple visualization of my results, where the x axis shows papers written throughout time and the y axis shows my qualitative determination for the impact that computers made on the research. This qualitative ranking is inherently somewhat subjective, but in general, 'None' means no computer usage needed, 'Partial/Simple' indicates computer usage that could have been done in earlier decades with weak computers, like basic computation, and 'Full' indicates complex computation that required relatively high-end computation.

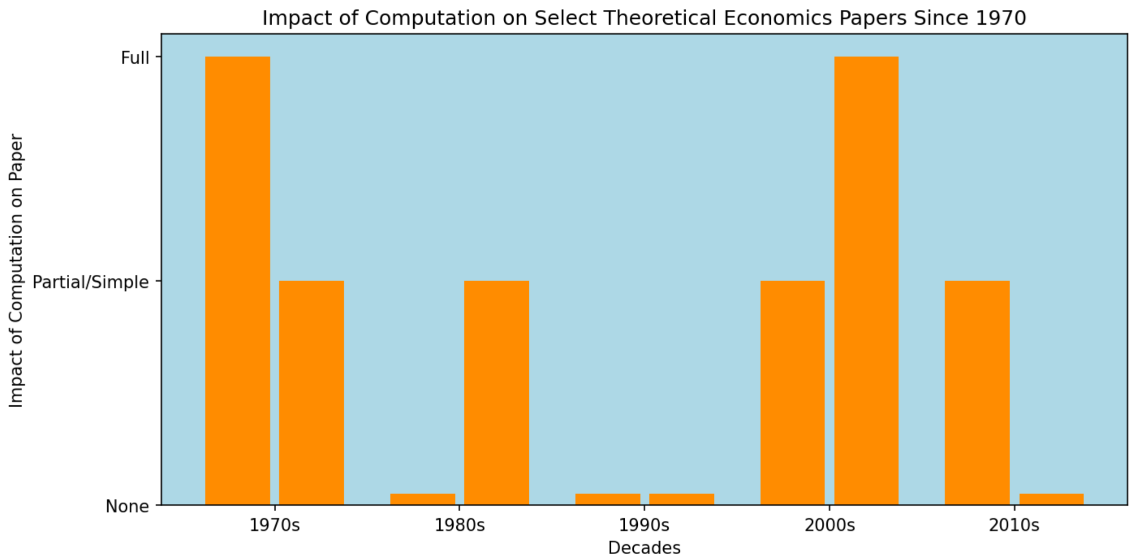

Figure 1. Results

In general, the complexity of the computation involved for papers that did use computation was quite low. Contrary to my expectations, there were no significant examples of simulations done (apart from off-hand citations) and the only real use of computation appeared to be in the analysis of large quantities of data. The only paper that significantly uses computation in a way that couldn't have been done decades earlier is Collier (2004), simply because of how extensively the models were created, tested, and analyzed, and the large quantity of data that was used to produce the models. In conclusion, the field of theoretical economics research has been transformed disappointingly little by the advancement of computation in the last five decades.

In general, computers work with numbers (specifically binary) and are exceptionally good at working with numbers, but computation is not good for directly addressing qualitative and conceptual issues. This may be why the field of theoretical economics research has failed to be transformed by computers. However, computation is good at producing evidence to *validate* theories, and this has not been used enough in economics research. Our advancing computation has given us the ability to produce increasingly complex models, such as machine learning models, allowing us to use data to both inspire theories and directly test them in the real world. This can be a valuable tool that not only improves the accuracy of our models and theories but improves the perception of them to the public and to other important institutions. With the fate of the country reliant on the conclusions that economic theories imply, why not use all the tools at our disposal to validate these theories?

The failure of theoretical economics researchers to use computers in their research is potentially a shortcoming that can be remedied in coming decades. The recommendation of this paper is that when economics researchers develop economic theories, they should work with applied economics researchers who have enough technical knowledge to test their theories. This can validate the integrity of the theory or provide further insights into its development. However, this should be taken with a grain of salt as more research is needed to determine *why* theoretical economics researchers have failed to use computers to a significant extent in their work; there may be very valid reasons. Additionally, the rise of generative AI, specifically large language models, might have a genuine impact on the field, since large language models can overcome the gap between quantitative and qualitative analysis that contemporary computers struggle with. For example, consider this very paper (this is technically an STS paper and not an economics research paper, but this is just an example). Computers were used very little in the writing of this paper as all the evidence and conclusions were conceptual. However, one could easily see how in the future, AI models might be used to skim not just two papers per decade, but hundreds or thousands of papers, and to then draw conclusions from what was learned. There is significant potential in the application of AI to economics research and should economics researchers fail to adequately incorporate contemporary computing in their work, it is likely that they will be late to using future computing as well.

A potential counterargument to my conclusions could be that analyzing the field of “theoretical economics research” is far too broad, and instead needs to be broken down by subfield. For example, papers analyzing theories of the firm may benefit little from computation, but papers on game theory or agent-based modeling would most likely be positively impacted by advanced computing, especially since these fields are becoming increasingly popular today. This is a valid counterargument and indicates potential for future research. However, my method of finding the most widely cited papers is a good proxy for how influential and popular each field is. I did not analyze agent-based modeling papers specifically because the field is not big enough to be significant in the field of theoretical economics research yet, as indicated by ABM papers not being the most cited. Another potential counterargument could be that qualitatively determining the impact of computing on a paper is fundamentally subjective and as an outside observer, I may have a misunderstanding or fail to fully grasp how much of a true impact computing made for each paper. This is also a valid argument, but the papers are all published and cited, so doubtful readers can verify my work for themselves. In future research, it may also be valuable to directly reach out to the authors of these papers to get their opinions, as this may be more accurate information.

Other future research in this topic may include analyzing the *best* ways to incorporate computation to improve perception and validity of models, analyzing how future computational advances like AI may be incorporated into theoretical economics research, and thoroughly analyzing more historical papers to expand on the work in this paper and gain an even deeper understanding of the impact of computing on theoretical economics research.

Conclusion

By looking at a sample of theoretical economics research papers since the advent of advanced computing and analyzing how they've been impacted by increasing computational power, this paper has been able to construct an understanding of how theoretical economics research has failed to fully integrate computation that could be used to further develop and validate economic theories. The reasons for this are complex and need to be further studied to be understood but are likely partially due to the status of theoretical research as primarily conceptual and qualitative, so researchers feel as though there's little value in incorporating computers. However, using computers to generate models and analyze and interpret data can be a convincing way to validate economic models and improve their perception by the public and other relevant institutions. In the coming decades, especially as the capabilities of computational systems are transformed by technologies like AI, theoretical economics researchers should reach across disciplines or expand their own technical capabilities to use computation to further benefit their own research.

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