

## CENTRAL PLANNING'S COMPUTATION PROBLEM

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*ABSTRACT:* Friedrich Hayek and Ludwig von Mises demonstrated that central planners will be unable to manage an economy rationally due to the problems of dispersed knowledge and the impossibility of economic calculation in a centrally planned economy. This paper adds to these two problems by suggesting a third: the computation problem. Drawing from realities found in computational economics, even if all the data is given and production is ignored, the size of the computational problem makes large scale central planning a practical impossibility. The size of the problem to be solved and limitations on computer processing power do not allow for computers to provide a solution to large scale economic problems in a time that is useful. For example, even under severe simplifying assumptions, distributing 80,000 heterogeneous consumer goods among six billion heterogeneous consumers requires a calculation that would take at least 10.5 quintillion years—when the Big Bang happened just 14 billion years ago.

*KEYWORDS:* central planning, economic calculation, computers

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## INTRODUCTION

Austrian economists have long recognized central planning's impossibility, especially because of the economic calculation problem (as demonstrated by Ludwig von Mises in many of his writings)<sup>1</sup> and the information problem (as demonstrated by Friedrich Hayek, most famously in his 1945 paper "The Use of Knowledge in Society"). These problems have demonstrated that rational economic planning is impossible without a market system with meaningful, informative prices.

As Mises describes, when all property is controlled by a central authority, there can be no exchange and therefore no meaningful prices, which makes cost accounting impossible. In Mises's words:

Separate accounts for a single branch of one and the same undertaking are possible only when prices for all kinds of goods and services are established in the market and furnish a basis of reckoning. Where there is no market there is no price system, and where there is no price system there can be no economic calculation. (Mises, 1981)

In short, without true exchanges of private property, there are no prices that can be used for cost accounting. This lack of cost accounting makes it impossible to evaluate whether a particular method of production is economical or wasteful.

Hayek describes the heart of the information problem in these terms:

Fundamentally, in a system in which the knowledge of the relevant facts is dispersed among many people, prices can act to coordinate the separate actions of different people in the same way as subjective values help the individual to coordinate the parts of his plan... Only to a mind to which all these facts were simultaneously known would the answer necessarily follow from the facts given to it. The practical problem, however, arises precisely because these facts are never so given to a single mind, and because, in consequence, it is necessary that in the solution of the problem knowledge should be used that is dispersed among many people. (Hayek, 1945)

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<sup>1</sup> Especially in *Socialism* (1981), though also in *Human Action* (1998) and *Economic Calculation in the Socialist Commonwealth* (1990)

Put another way, we can imagine a solution to the problem of central planning if all of the information regarding preferences, production, and available resources were given to a single mind. However, from a practical standpoint, all the facts never are given to a single mind.

These two problems make rational economic planning impossible if a central authority attempts large-scale planning. However, the rise of increased computing power since the late 1950s has led some to suggest that the calculation problem and information problem can be overcome by computers.<sup>2</sup> As early as 1967, Oscar Lange ventured the claim "Were I to rewrite my essay [refuting Hayek and Robbins's criticisms of central planning] today my task would be much simpler. My answer to Hayek and Robbins would be: so what's the trouble? Let us put the simultaneous equations on an electronic computer and we shall obtain the solution in less than a second." Such a claim overestimates the ability of computers to process information. This paper establishes that a "computation problem" would make large-scale, consumer-oriented central planning impossible, even in the absence of the calculation and information problems.

## DODGING MISES'S AND HAYEK'S CRITICISMS

Throughout history, advocates of central planning have underestimated its difficulty. These advocates ignore or dodge the problems presented by Ludwig von Mises and Friedrich Hayek, and modern-day advocates<sup>3</sup> of a computerized form of central planning have continued this tradition. For example, Cottrell and Cockshott (1993) revive Lange's earlier market socialism arguments, and argue that computation in labor costs is a rational basis for economic calculation that is computationally feasible with modern technology. Thus, they

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<sup>2</sup> As far back as 1908, Barone claimed that one could run an economy without private property "in principle"—suggesting that the set of mathematical equations was well-defined, and had a solution. (Mises, 2000) This claim was echoed by Dickinson (1933).

<sup>3</sup> Among modern day advocates are futurist Jacque Fresco and the Zeitgeist Movement. Though the two have little academic backing, they command a significant popular following. For example, the Zeitgeist Movement has over 1000 chapters in over 70 countries—and its de facto leader, filmmaker Peter Joseph, has spoken to sold-out crowds of over 900 at "ZDay" events.

sidestep Misesian calculation problems by providing a method of calculation using non-monetary units. They admit that calculating costs is insufficient without some measure of consumer preferences. To solve that problem, they suggest (following Marx) that consumers will allocate "labor certificates" among the various goods that they may purchase. Thus, the Hayekian information problem is sidestepped by allowing consumers a market-style means to express their preferences, and through the revelation of labor costs through observation. All that remains is to use computers to determine the proper allocation of labor time.

However, by incorporating modern "happiness research" (as described, for example, by Frey and Stutzer [2002]), one could speculate about eliminating the "labor certificate" method and instead use individual "utilities" drawn from happiness studies. Through this method, one could eliminate the need for adjusting the "labor certificate price" of consumer goods, and instead distribute goods so that they will create the maximum total social utility. In a world where computers are pervasive, gathering the needed information seems possible.

This paper seeks to address a system in which computers have replaced markets. In such a system, Mises's and Hayek's economic problems will appear, but a third independent, technological problem would appear as well: the computation problem.<sup>4</sup> The computation problem attempts to meet those that advocate computerized, automated central planning, as far as possible, on their own terms. In exposing the computation problem, we will allow for a number of unreasonable assumptions. The computation problem will show that, as long as we hold to a few touchstones with reality, computers will be unable to run an economy, as long as they consider individual preferences.

## THE UNREASONABLE ASSUMPTIONS

Some of the following assumptions are necessary to allow the possibility of an economy run by computers. Others are an attempt

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<sup>4</sup> Hayek hinted at this problem when he stated that "what is practically relevant here is not the formal structure of the system, but the nature and amount of concrete information required if a numerical solution is to be attempted and the magnitude of the task which this numerical solution must involve in any modern community." (1990, p 208)

to speak to the advocates of computerized central planning on their own terms. In short, this paper attempts to give computerized central planning the best chance it can, so that when it is proven impossible in a simplified case, it will clearly be impossible in a more complicated, realistic case.

**ASSUMPTION 1: UTILITY CAN BE COMPARED INTERPERSONALLY.**

If the computer is going to determine the distribution of scarce resources, utility must be interpersonally comparable, as resources can be distributed among people in a number of possible ways. For the computer to determine whether a particular resource should go to Person A or Person B requires an interpersonal comparison of utility.<sup>5</sup> This assumption will allow for a simple maximization of social utility, as long as one additional assumption is made.

**ASSUMPTION 2: UTILITY HAS A SIMPLE, CARDINAL,  
FUNCTIONAL REPRESENTATION.**

Mises has argued that preferences are strictly and inescapably ordinal.<sup>6</sup> However, ordinal preferences do not allow for any possibility for interpersonal comparisons of utility, nor for a computation of total social utility. If a computer is going to determine the distribution of scarce goods, then it must be able to compare utility interpersonally, and that requires a cardinal representation for utility. To keep the computational problem as manageable as possible, the form chosen must be simple as well. In this case, utility functions will be assuming a quadratic form, with some interaction among goods being allowed (so the utility of consuming one good may

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<sup>5</sup> An alternative method is possible. The computer could begin with an arbitrary distribution of goods, and then consider possible trades and "swap" goods whenever a trade would be mutually beneficial. In order to be economically efficient, this routine would have to be computationally intensive, as the computer must consider a long chain of possible trades—the type of chain that, in a monetary economy, would be facilitated by the use of a medium of exchange. An interpersonal comparison of utility allows for a simpler algorithm: maximizing total social utility.

<sup>6</sup> From *Human Action*: "Action sorts and grades; originally it knows only ordinal numbers, not cardinal numbers.... There are in the sphere of values and valuations no arithmetical operations; there is no such thing as a calculation of values." (1998)

be affected by the quantity of another good consumed). However, this interaction is restricted to be through simple multiplication. Under these strict mathematical assumptions, the maximization problem will simplify to solving a system of linear equations—the type of problem that computers are fastest at solving. This is also a problem for which there is a well-known formula for how many floating point operations, and therefore how much time, such a problem requires to solve.<sup>7</sup>

**ASSUMPTION 3: A COMPUTER WITH PERFECT INFORMATION ABOUT UTILITIES AND AVAILABLE RESOURCES.**

The computer must have complete knowledge of each individual's utility function,<sup>8</sup> and of the resources that are available to satisfy consumer wants. To maximize social utility, constrained by available resources, the computer must have information regarding resource constraints and the utility to be maximized.

**ASSUMPTION 4: NO PRODUCTION.**

This assumption is included for reasons of computational simplicity. Allowing for production requires making assumptions regarding the form and stability of production functions. While no advocate of computerized central planning would suggest that such an assumption is even close to reasonable, it is computationally easier to solve a distribution problem alone than to simultaneously solve a distribution problem and a production problem.

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<sup>7</sup> For a precise solution, the fastest known method is called "Gaussian elimination." Such a method requires  $(2/3)n^3 - n/3$  floating point operations to complete, where "n" is the number of equations in the system being solved. (Trahan, Kaw, and Martin)

<sup>8</sup> Here, the argument assumes away the objection raised in Mises (2000) that "Those who think that it would be possible to apply the equations of mathematical economics for making the calculations fail to see that included among the items of which these equations are composed are unknown preference scales belonging to a situations which is unreal and can never be realized in practice. The circumstance that they are unknown frustrates all attempts to use the equations for purposes of economic calculation."

This assumption also sets aside the objections posed by Murphy (2006). Murphy attacks the argument that a socialized economy can set aside the direct computation problem and simply do what the market does—have a vector of prices that the planners adjust until equilibrium is achieved.<sup>9</sup> Murphy notes that such a system would require that the planners have a set of prices not just for all existing goods, but for all conceivable goods—and such a list is uncountably infinite. The computation problem, however, exists even when there is no production—so that the number of goods being dealt with is finite.

At this point, it is worth noting that Hayek's and Mises's objections to central planning have been assumed away. Assumptions 1, 2, and 3, when combined, eliminate the Hayekian information problem. Assumption 4 eliminates the Misesian calculation problem.

## **TOUCHSTONES WITH REALITY**

### **TOUCHSTONE 1: PREFERENCES ARE HETEROGENEOUS.**

Without this assumption, the problem of distribution would vanish immediately. If each person is identical in his preferences, then to find how much of each good a consumer should receive, one simply has to divide the quantity of the consumer good by the number of consumers. This computation would require very little time. For any computation problem to arise in the absence of production, heterogeneous preferences must exist – as we know they do in reality. This touchstone prevents us from being able to use the assumption of a “representative agent”. Assuming heterogeneous preferences is also fair, as advocates of central planning typically want to allow for consumer individuality. (Thus the mock consumer markets advocated by Cottrell and Cockshott (1993).)

### **TOUCHSTONE 2: CONSUMER GOODS ARE HETEROGENEOUS.**

Like individual preferences, consumer goods are heterogeneous. This is also recognized by advocates of central planning. This

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<sup>9</sup> Much like what Cottrell and Cockshott (1993) recommend for consumer goods markets.

heterogeneity increases the size of the computational problem by expanding the number of distribution problems that must be solved.

### TOUCHSTONE 3: CURRENT LIMITS ON PROCESSING POWER

The final touchstone with reality is the simple fact that computer processing power is limited. While we rarely notice the limitations of processing power on the low-powered personal computers that most of us use, the reason is that we rarely ask computers to solve difficult problems. The process of typing in a word processing program is computationally straightforward: the computer receives input from the keyboard, stores appropriate data to memory, and sends appropriate signals to the monitor to make letters appear. Even so, nearly anyone who has used a computer for long has experienced a computer “lagging.” This phenomenon occurs when a computer is asked to perform enough operations in a short enough time frame that the computer processor is a bottleneck. This anecdotal experience demonstrates a simple fact: when we ask computers to perform a large number of computations, it takes them time—and sometimes a noticeable amount of time—to perform them.

As we frame the computation problem, then, we have to account for the fact that processing takes time. To provide a limiting case, this paper assumes that processing speed is limited by the combined processing power of the TOP500 supercomputers—the 500 fastest supercomputers in the world.<sup>10</sup> Supercomputers’ processing speed is measured in “FLOPS” (floating point operations per second). The combined power of the TOP500 supercomputers as of June 2013 can perform 233 petaflops (that is  $233 \times 10^{15}$  FLOPS, or 233 quadrillion FLOPS) ([www.top500.org](http://www.top500.org)). By combining the formula for the number of floating point operations required to solve the problem with the processing speed of the TOP500, we can arrive at a reasonable lower limit on the processing time required to solve the computation problem.<sup>11</sup>

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<sup>10</sup> One might wonder whether cloud computing could approach the power of supercomputers. On that question, the answer appears to be no. (Napper and Bientinesi, 2009)

<sup>11</sup> While it is true that the selection of the TOP500 supercomputers was, to some degree, arbitrary, it was informed by two points: (1) the TOP500 have a well-



## RESULTS

### SCENARIO 1: A SMALL COMMUNITY WITH FEW GOODS.

To begin, consider a small community of just 1,000 people with 1,000 different consumer goods that they are trying to distribute among them. When compared to a real economy, this one is quite small. However, the system of equations required to solve the problem involves 1,001,000 equations,<sup>12</sup> which will require approximately 669 quadrillion floating point operations to solve. Using the TOP500 supercomputers working in parallel, this problem is solved quickly: in just over 3 seconds. To most people, a 3 second wait for an important answer is not unreasonable. Yet, Lange's claim of obtaining the solution "in less than a second" is false, even for this small-scale problem.

### SCENARIO 2: THE POPULATION OF THE US WITH FEW GOODS.

Suppose now that we have a much larger population—300 million, which is a bit less than the United States' current population. To keep the problem simple, assume that the population only has 100 different goods available to them (a drastic simplification). The computation to distribute these goods requires just over 30 billion equations. If the relationship among floating point operations and the number of equations were proportional, then this computation would require about 38 days. However, the relationship among the number of equations and the number of operations is not proportional—each new equation interacts with all the others to change the solution. These interactions require additional operations. As a result, the computation for this scenario requires 2.6 million years, a clearly impractical length of time.

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documented processing power. (2) Odds are quite small that the TOP500 supercomputers—or their equivalent in processing power—would be available to solve the computational problem presented in this paper. As a result, using them should provide a reasonable minimum computational time required.

<sup>12</sup> This would include, from the maximization routine,  $1,000 \times 1,000$  first order conditions—the number of consumers multiplied by the number of goods—plus 1,000 constraints to ensure that all of the consumers goods are used.

### SCENARIO 3: GLOBAL ECONOMY WITH MANY GOODS.

Scenario 2 has shown that a computer-managed economy runs into difficulties, even if the population is a small fraction of that of the globe and even if the number of goods is less than any person probably has in eyesight. To fully appreciate the full scale of the problem, we should size it up to a more realistic level. Suppose that there are 6 billion people on Earth (approximately a billion less than there are) and that there are 80,000 different consumer goods (the number tracked for calculating the Consumer Price Index in the United States). This system requires 480 trillion equations to solve.<sup>13</sup> To solve these equations, it would take the TOP500 supercomputers 10.5 quintillion years.<sup>14</sup> According to recent estimates by cosmologists, the Big Bang happened approximately 14 billion years ago. So, a computer that started this computation in the moment of the Big Bang would be approximately 0.00000013% of the way done with the calculation. Even if computers are asked to solve a simple economic problem—determining the distribution of a fixed set of consumer goods—the problem is insurmountable if we try to account for heterogeneous goods and heterogeneous preferences in a large economy.

## REAL WORLD COMPLICATIONS

### THEORETICAL MAXIMUM ON PROCESSING POWER

One possible objection to the argument thus far is that it does not account for “Moore’s Law.” Moore’s Law, first proposed by Gordon Moore in 1965, suggests that the number of transistors that can fit on a microchip will double approximately every 18 months. This trend had been observed starting in 1958 and continued until about 2010. Since that time, the trend has slowed somewhat, but current forecasts suggest that the doubling will happen about every three years. This suggests that our processing speeds will continue

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<sup>13</sup> So, Murphy (2006)’s claim (echoing Hayek) that the system would take “millions or billions” of equations understated the problem by several orders of magnitude!

<sup>14</sup> For comparison, some cosmologists suggest that in 1 quadrillion years, the solar system will fall apart, as passing stars will lead planets to deviate from their orbits.

to improve indefinitely. So, at some point in the future, even the global economy problem may be solved in a reasonable amount of time.<sup>15</sup> However, physics informs us that there is a theoretical limit on the processing power of computers.

A quantum computer processes information by changing the quantum state of the processor's components. However, there is a limit to how fast quantum states can evolve. Using these insights, physicists have found that the fundamental limit is approximately 10 billion times faster than most contemporary computers (Levitin and Toffoli, 2009). Supposing that computer processing is 10 billion times faster than the TOP500 (still ruled out by the research done by Levitin and Toffoli, as the TOP500 are far from representative) allows for the time in Scenario 3 to decline from 10.5 quintillion years to just 1.05 billion years—taking us from long before the Big Bang to a time approximately when multicellular organisms were beginning to form on Earth. So, even allowing for more than the maximum theoretical improvement in processing speed, the computation problem is still insurmountable.

## INFORMATION TRANSFER LIMITS

In addition to limits to processing speed, there are also limits to the speed at which information can travel. When processors solve problems, they receive inputs from other components of the computer—and that input can arrive no faster than the speed of light. So, the speed at which even an instantaneously processing computer can perform tasks is limited by the physical distance between the processor and the other components with which it interacts (in the case of a supercomputer, these other components include a number of other processors). While the speed of light is quite fast compared to the small distances that must be traveled inside a standard computer, the number of required calculations increases the total distance that must be traveled. For example, suppose that a processor is separated from the memory that it uses to store the problem and solution by just 1 centimeter. If just 1 quadrillion floating point operations

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<sup>15</sup> Though for the global problem to be solved in less than 1 year, it would take 130 years of Moore's law to get the TOP500 to that point.

have to be performed, then light must travel 10 trillion meters to solve the problem—which takes approximately 30 seconds. Under these conditions even the fast problem covered by Scenario 1 would take over five and a half hours to solve, even if the processing was instantaneous. In the global scenario, the transfer of information would add nearly 78 septillion years to the computation. In this problem, the information transfer time is approximately 2 million times the processing time—though this time could be reduced if the space between the processor and the memory were less than 1 centimeter.

## PRODUCTION

Apart from the physical realities that stand in the way of computers being able to solve the computation problem, there is the reality that the economic problem is far more difficult than the one discussed in this paper. In reality, the economic problem is not simply one of distribution—it is also one of production. With extreme simplifying assumptions (homogeneous capital and labor, for example), the problem of production is small compared to what we have discussed already, so it adds little to the computation time—but if we allow heterogeneous capital and heterogeneous labor, then the number of equations increases substantially.

But, there is an even larger problem from a computational standpoint: production functions—even if they are assumed to be simple—are almost certainly not quadratic.<sup>16</sup> So, the system of equations that must be solved is no longer linear. Once we move away from linear equations, different—slower—techniques must be used to solve the system. Two of the most common techniques are Newton's Method (or the "tangent method") and Broyden's Method (or the "secant method"). Both methods involve first inputting one or two guesses, and then approximating the nonlinear system of equations with a linear system of equations using those guesses, and then solving that linear system. After the linear approximation is solved, the system of nonlinear equations is checked to see whether the approximate solution to

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<sup>16</sup> Diminishing marginal returns is sufficient to prove this because a quadratic production function would have increasing marginal returns.

the linearized system fits within some tolerance (chosen by the programmer) of being a true solution to the original nonlinear system. If it is within the tolerance, then that solution is considered to be a “good enough” solution to the original system. If it is not, then the proposed solution is considered to be a new “guess” and the process goes through another iteration, continuing until a good enough solution is found.

Programming Newton's Method is more demanding, as the programmer must provide formulae for every partial derivative of every equation in the system. These are used with a single initial “guess” to create the linear approximations. Though the programming is difficult, Newton's Method tends to converge upon a solution relatively quickly (its rate of convergence is “quadratic”). Broyden's Method is easier on the programming side, as it does not require any programming of partial derivatives. Instead, it uses the results from two initial guesses to approximate the partial derivatives, and then proceeds similar to Newton's Method. However, because Broyden's Method involves two layers of approximation (approximation of the nonlinear equations by linear equations and approximation of the partial derivatives), it tends to take more iterations to converge on a solution (its rate of convergence is only “superlinear”—which is somewhat slower than “quadratic”).

In either case, the length of time taken to arrive at a solution is somewhat larger than the number of iterations needed to arrive at a solution multiplied by the time required to solve a linear system of an equivalent size to the nonlinear one. (The additional time is required to compute or approximate the partial derivative matrix and to evaluate the solution.) There is no reliable a priori way to determine how many iterations will be required to solve a nonlinear system, as the number depends on how nonlinear the system is, how good the initial guess is, and how stringent the solution tolerance is. However, in practice, Newton's Method often converges in four or five iterations, with Broyden's Method taking two or three more. So, if a system the size of the one in Scenario 2 were nonlinear rather than linear, it would likely take over 40 million years rather than just under 10 million years to solve, if it took four iterations to arrive at a solution.

## COMBINING THE PROBLEMS

Though processing time alone should be sufficient to prove that computer-managed central planning is impossible even in the simplest case, it may be instructive to put all the realistic problems together to get an estimate of just how difficult the problem would be. Using the global scenario, processing time requires 10.5 quintillion years, information transfer (assuming a 1 cm distance per calculation) requires 78 septillion years, and including simple nonlinear production functions would multiply these results by the number of required iterations—four being a reasonably low estimate. So, the global problem would take approximately 312 septillion years to solve. Even in the simplest case of Scenario 1, allowing for information transfer and production increases the computation time from 3 seconds to nearly a full day.

This proves just how remarkably difficult the computation problem is to solve. Even if processing were instantaneous, information transfer limits would pose a serious problem (perhaps more serious than processing), and any time that is required will get multiplied if the system is allowed to be non-linear.

## ECONOMIZING THE SUPERCOMPUTER AS A RESOURCE

Suppose, now, that we solved all these problems so that supercomputers could solve the economic problem quickly enough to be useful. Does it then follow that it is economical to use them this way?

Once we recognize that the computers doing the calculations are themselves resources with multiple potential uses, the answer to this question is not obvious. Solving the economic problem—how best to use scarce resources to satisfy human wants—is a valuable endeavor. But, as Ludwig von Mises points out when discussing the calculation problem, what we want to do is ensure that we do not give up any more valuable end while satisfying a less valuable end.<sup>17</sup> To evaluate whether this is the case, we should consider

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<sup>17</sup> “[The teaching of technology] ignores the economic problem: to employ the available means in such a way that no want more urgently felt should remain unsatisfied because the means suitable for its attainment were employed—wasted—for the attainment of a want less urgently felt.” (Mises, 1998)

alternatives. In particular, consider the use of a computer to solve the economic problem and the use of a market system.

A market system that includes private property rights, profits and losses, and market prices provides information about the relative importance of various wants, the means of performing economic calculations to ensure a minimal waste of resources, and an incentive to provide for the most valuable ends. The market does not perform these tasks "perfectly"—errors will be committed.<sup>18</sup> However, errors tend to be temporary and small, as entrepreneurial errors lead to losses and consumer errors lead to regret. Those that commit error then have every reason to change course. None of this requires that a central processing unit perform a large number of related operations. In a sense, there is a division of processing that happens as each individual entrepreneur, consumer, and resource owner makes their own determinations about what is the best course of action.

A computer that is capable of solving the economic problem is also capable of solving other large-scale problems that the market cannot solve. Setting aside information and calculation problems, a computer could provide two benefits: first, it could solve the economic problem without error, and second, it could free up less powerful computers that are currently used to partially solve the economic problem. But, if errors are expected to be small in a market system, then is it worth setting aside the solution of entire scientific problems (or shifting those solutions to the newly-freed-up less powerful computers) to eliminate small, temporary errors? Whether it is worth the sacrifice is a matter of preference, but the one choosing must be informed that they are making the solution of one problem impossible (or at least less timely) when they use a high-powered computer to eliminate small errors in the market's solution to the economic problem. Even in this idealized situation, it seems unlikely that the computer's best use is to replace the market system.

## A COMPARISON OF CENTRAL PLANNING'S PROBLEMS

Having identified the impossibility of computation in any reasonable period of time for a large-scale economy, one must

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<sup>18</sup> See, for example, Mises (1998): "The socialists, it is true, object that economic calculation is not infallible. They say that the capitalists sometimes make mistakes in their calculation. Of course, this happens and will always happen."

distinguish the nature of this problem from Mises's calculation problem and Hayek's information problem.

At heart, the computation problem is about information processing, and the inability of computer technology to provide a fast solution to a large system of equations, with the observation that even simple economies that allow for good and preference heterogeneity must require very large systems of equations to describe them. As such, the computation problem is really a technological one more than an economic one—that is, the computing power available is incapable of solving a computational problem the size of the worldwide economy.

In contrast, Mises's calculation problem is about the centrality of needing a common unit in order to compare various productive enterprises. Money prices provide that unit of account, and, when money prices reflect individual preferences, result in calculations that guide an economy toward a rational path. The computation problem assumes away this issue by allowing a direct comparison of utility units. The calculation problem also vanishes in the absence of production. If one is only considering the distribution of a fixed set of consumer goods, the calculation problem is not present—as there is no production, there is no need for economic calculation. The computation problem, however, exists even in the absence of production.

Hayek's information problem concerns the dispersed nature of knowledge regarding means and ends. Money prices summarize the relevant knowledge regarding a particular good—whether it be a consumer good or a producer good. If it were possible to transfer all the necessary knowledge to a single mind, Hayek himself argues that the economic problem is not particularly difficult. "On certain familiar assumptions the answer is simple enough. *If we possess all the relevant information, if we can start out from a given system of preferences, and if we command complete knowledge of available means, the problem which remains is purely one of logic.*" (Hayek, 1945) The computation problem calls into question this claim—processing the information is a time-consuming process that grows more complicated the more information there is. This is true even if the process takes place in a "single mind" (or chain of networked supercomputers).



**Table 1. Central Planning's Problems Compared**

<b>Problem</b>	<b>Calculation</b>	<b>Information</b>	<b>Computation</b>
<b>Key Assumptions</b>	Single owner of capital goods	Dispersed knowledge	Heterogeneous consumers and goods
<b>Nature of Problem</b>	No unit to compare various production methods	No single mind has information needed to plan	Limited computational power
<b>Market Solution</b>	Profit and loss calculation	Prices summarize relevant information	Entrepreneurs and consumers perform division of computation

## CONCLUSION

In the end, the prospect of a computer-managed “resource-based” economy is nothing more than a fantasy. Even if we allow for information problems and calculation problems to be assumed away, the information processing requirements in a modern economy filled with heterogeneous goods and heterogeneous consumers is greater than even the most powerful supercomputers—even in theory—can handle. Thus, the claim by Barone (1908) and Dickinson (1933) that a solution to the equations governing an economy is possible “in principle” should be called into question—once we take account of not just the principles of mathematics but also the principles of physics and cosmology, the solution of a much simpler problem is impossible—and, by extension, so is the solution of the computation problem in the real world.

The computation problem also carries with it implications for the possibility of using mathematical or computational economic models to provide good advice to policymakers about how to make economic policy that may benefit society. To put it briefly: such models are going to be limited in their usefulness. The computation problem shows that computation is only possible if we set aside some level of heterogeneity of consumers or goods. However, setting aside such heterogeneity when making policy decisions will lead to poor outcomes. One size does not fit

all—acting as if it does is going to harm consumers. But, in as far as we adopt the reasonable assumption of consumer heterogeneity, the computation problem becomes insurmountable.

However, the computation problem does not prove that it is impossible to run an economy without a market system. One can set aside all concerns about fulfilling consumer wants. Then, not only is computation easy—it is unnecessary. Allocate resources according to any arbitrary set of rules. Then again, that is a system that few consumers would desire.

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