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An Essay in Favor of Dynamic Partial Control of the Economy

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ABSTRACT

This paper applies recent innovations in the study of dynamic chemical structures to economic systems. Partial control of chemical process systems, especially chemical reactors, has features similar to those of economic models, namely: complexity, non-linearity and an inability to formulate accurate mathematical models explaining their behavior. Rather than trying to fully control the chemical reactors, or the model of the economy, and fail because of impracticability, partial control involves identifying only key variables that monitor the system. Monitoring only a few variables allows for studying and controlling the system.

JEL Classifications: *P1, R1, E5, F4, L6, F1, R1*

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[**] Distinguished Professor Reuel Shinnar has recently passed away. Dr. Shinnar served as the Distinguished Professor Emeritus of Chemical Engineering at the Grove School of Engineering at The City College of New York and was an expert on chemical design and process control.

I. INTRODUCTION

There are parallels between complex chemical processes and economic systems. Both systems share the characteristics of complexity, non-linearity, and an inability to write accurate mathematical models explaining their behaviors. Chemical engineers have addressed these characteristics in chemical reactors by developing a model called partial control (e.g., Kothare et al., 2000; Shinnar, et al., 2000; Tyreus, 1999A, 1999B; Mismar and Ismail, 1998; Arbel, et al., 1997; Ahmed, 1996; Arbel, et al., 1996; Guettler, et al., 1994; Jacobsen and Skogestad, 1994; Yu, 1993). This type of model has also been successfully employed by material science engineers (Nordmann and Cheng, 1997), computer sciences scholars (e.g., Pomeranz and Reddy, 1993, Aracil and Gordillo, 2000), and electrical engineers (e.g., Edirisooriya and Robinson, 1993). In a similar way, game theorists studying the delayed information model have used frameworks with noise-corrupted features. By using Monte Carlo simulation estimations and Kalman filter-type estimator, they show that pursuing such a strategy substantially improves the accuracy of the model (Shinar and Glizer, 1999, Shinnar, et al, 2000, Emirmahmutoglu, et al., 2008).

This model allows engineers to monitor complex chemical reactions and change only number of key variables, in order to move the system to a different state or level. This property of being able to control for only a few variables out of a complex system is also common when one studies economic regimes. Due to the similarities between chemical and economic processes, it is worthwhile to examine a framework for applying partial control to economic systems. This paper is an effort to provide such a framework.

Partial control methodology can also be adopted and applied in education. Green and Carl (2000) test a number of schools under a similar partial control system in various major cities to examine the important issues concerning their low performance. Jessell, Madura and Picou (1993), and Spencer, Akhigbe and Madura (1998) apply partial control theory to business acquisitions, focusing on the before-and-after impacts in market performance and policy controls. Weskamp (1988) investigates the relationship between credit contract and bankruptcy using the partial control mechanism in comparison to total control system. Ooghe and Peichl (2011) use a partial control environment to formalize the idea of “fair and efficient” taxation. Robert (1993) presents a different mathematic approach based on Markov Chain Monte-Carlo methods, toward partial control algorithms based on functional and mixing theories (see also Verhofen, 2005).

By introducing a “hybrid” system, Tang, Choy and Wat (2000) apply a partial control system framework to office development decision-making in Hong Kong. They find that the “hybrid” system offers necessary certainty supports for the decision controls. Similarly, Kang, Choe and Park (1999) use a hybrid method combined with an inductive learning and neural networks in order to control and generate better operating manufacturing conditions.

With an attempt to propose an optimal nonlinear effluent-charge system for pollution control, Lee and Kim (2000) compare their pollution control system with other conventional linear effluent-charge systems and discuss the economic implications of implementing such systems. Young, Parkinson and Lees (1996) conduct a statistical control modeling procedure for environmental studies. They provide three main methodological tools: uncertainty and sensitivity studies based on Monte Carlo simulation techniques; dominant mode analysis using a new method of combined linearization and model-order reduction; and data-based mechanistic modeling. Additionally, Pandey (2005) utilizes the Industrial Pollution Projection System database to predict pollution load and related abatement costs. The analysis juxtaposes the cost effectiveness of effluent charge versus regulation.

In a Just-In-Time (JIT) production environment, Albino, Dassisti and Okogbaa (1995) model a *Kanban* discipline system (*Kanban*, a Japanese term for “visual record”, is a time-base management technique originally developed in the Toyota assembly line that directly or indirectly drives many of the manufacturing organization in Japan). This *Kanban* system permits reliable evaluation of manufacturing system performance in terms of improved time utilization. Holl, Pardo and Rama (2010) concur with the idea that in regards to production subcontracting, just-in-time strengthens the importance of proximity.

The idea of observing relatively few variables enabling policy makers to better control the economy is in line with the recent Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel, where both Sargent (1976, 1978, 1979, 1983, 1987, 2001), Sims (1972, 1980, 1986, 1987, 1992, 1993, 2003, 2006) and Sargent and Sims (1977) use a limited number of variables to study monetary and fiscal policies. In this way they are able to perfect the art of distinguishing between cause and effect in the macroeconomy (see also, Birati and Shachmurove, 1991, 1993; Christiano, et al., 1999; Friedman and Shachmurove, 1996, 1997, 2005; Shachmurove and Shachmurove, 2008; Shachmurove, 2005, 2006).

The remainder of the paper is organized as follows. Section II elaborates the idea that for modeling and monitoring purposes, chemical reactors and economic systems share the same characteristics. Section III describes the methodology of partial control. Section IV details the minimum information required for the partial control model. Section V applies the insights of partial control to global economic markets. Section VI concludes.

II. CHEMICAL REACTORS AS AN ANALOG FOR ECONOMIC SYSTEMS

Chemical process systems have some features similar to those of economic systems, namely: complexity, non-linearity, and an inability to write accurate mathematical models describing them and their behavior (Shinnar, 1990A). Adiabatic reactors, which make up the majority of large chemical reactors, are a class of reactors that can provide particularly useful analogies.

In order to drive its system, adiabatic reactors rely on their own heat generated from the reaction. Unfortunately, such a reactor has an additional steady state (the null state) where nothing happens. The system can crash to this null state when a large perturbation occurs. It can also have steady state solutions that, while linearly stable, are inherently unstable to large perturbations. In the absence of accurate models, one often does not know the reactor range for steady state operation. This creates control problems similar to those in economics. Such control problems have been solved in chemical reactors by using partial control models.

Control basically has two different approaches: total control and partial control. Two extreme examples illustrate these approaches. In an airplane, total control is needed. A design is required that permits a thorough understanding of how every item functions, or in the language of control, a fairly accurate and complete model that allows exact control of all essential functions. In contrast, in a complex chemical reactor, often a very limited knowledge about the reaction exists. Catalysts promoting the reaction can change during operation or due to replacement. Only imperfect models exist.

Another difference between total and partial control is the use of inputs to control variables. In total control, for every variable to be exactly controllable, a single modifiable input that can be manipulated is needed (Shinnar, 1990A). In the airplane example, certain controls such as throttle, aileron, elevator, rudder, etc. are inputs to control variables such as speed, pitch, yaw, etc. (Oster, Strong, and Zorn, 1992, Sontag, 1998). In chemical reactors, as well as economics, many more variables require control with inputs that can be manipulated. This condition necessitates partial control (Shinnar, 1990A).

Experience has taught that several key variables can adequately control these complex systems with very few inputs (Shinnar, 1990A). Properly choosing the variables and the set points, and changing those set points in response to system changes can keep the system stable within acceptable limits. This approach forms the foundation of partial control.

Although partial control models are not exact, minimum information about the system is needed. In control theory this fundamental difference has not always been recognized. Shinnar and Glizter (2000) show that, due to uncertainty in many chemical processes, optimal control methods developed in aerospace are impractical for a large class of problems in the chemical industry. Consequently, efforts should be directed at concentrating on control with minimum system information. Compared to chemical reactor control methods, economic control methods suffer from a greater lack of accurate models.

In economics, total control and partial control have been employed. The communist system tries to achieve total or exact control by directly controlling all economic activities. In the absence of very accurate models, such an attempt is doomed to fail. The western economy relies to a large extent on the free market to drive and control the economy. This approach uses money flows as internal control circuits to direct and control underlying economic activities, such as production. Although a capitalist economy with an invisible hand is similar to an adiabatic reactor running on its own heat, the economy may benefit from limited control to maintain the desired steady state. All governments try to maintain some control (Shinnar, 1990A).

In the U.S., the agency that uses actual methods of feedback and control similar to those used by an engineer is the Federal Reserve System (Fed). The Fed reevaluates its policy at intervals by examining various economic parameters such as inflation growth and unemployment. The Fed then tries to keep them within specific limits by manipulating interest rates. However, it is difficult to control a complex reactor, much less a complex economy with a single manipulated variable. There is no coordination of the Fed with any other macroeconomic policy, such as fiscal stimulus. An example of poor policy coordination is tax cuts combined with monetary stimulus.

In order to utilize partial control for the purpose of influencing the economy, a better understanding of this model is essential. This is where the concepts of partial control developed in chemical processes could provide some guidelines and a framework for discussion.

III. METHODOLOGY OF PARTIAL CONTROL

The steps to develop a partial control model are indicated below. The order of completion is not relevant (Shinnar, 1990A).

1. Define the system to control.
2. Define the goals of control. For the reactor these are output quality and production rates. Ensure that the goals and specifications are consistent with system capabilities.
3. Develop a model for the system. Evaluate the model for minimum information requirements and sources. Include critical processes and constraints. Feedback control requires minimal information. Transitioning between steady states requires additional information.
4. The inputs must be evaluated to determine which ones can be manipulated and what the input constraints are. In a reactor, this is preferably done in the design stage.
5. Evaluate measured variables chosen for the set points with respect to the possible interaction between control loops.
6. Analyze the potential perturbations and changes imposed on the system. Filter the inputs to control perturbations. Reduce the ranges over which inputs and perturbations can vary and limit the rate of any change. Filtering inputs is one of the most essential parts of process control.

No political body exists that can implement economic partial control on a global basis. The global economy should be divided into independent sub-units large enough to operate independently. Subsequent macro-policy can then be coordinated. For example, the U.S. economy is large enough to operate as an independent sub-unit of the global economy. U.S. policy makers may raise domestic growth rates with partial control methodology. Next, coordination with other sub-units such as the European Union should occur. A network consisting of a policy authority and self-sufficient sub-units is required. This structure is described below (Shinnar, 1990B).

IV. MINIMUM INFORMATION REQUIRED

In a plant, the first task in designing a control system is to define the specifications of the products and the desired production rate. Specifications also include hard process constraints. While product specification and product goals in a chemical plant are dictated by market demand, those goals have to be coordinated with capabilities. Limits of the process are difficult to establish a priori, but have to be understood for the purpose of successful control. In an imperfect economic system, we rely on feedback loops in our models to optimize results (Shinnar, 1990A).

Defining goals for the economy is challenging since there is no immediate consensus. Should policy be aimed at macroeconomic stability, increased growth, or distributional equality with lower output? Other policies to consider are environmental remediation and business cycle moderation (Shinnar, 1990A).

In order to control a system around a specific steady state, linear models can be used based on identification, or statistical correlations. The latter can be quite powerful.

Global linear models are useful to maintain system stability or change steady states. One may argue that global linear models are preferred to statistical models in a given steady state even if they are less accurate. Statistical correlations or linear models cannot predict constraints, multiple steady states, business cycle behavior, and which steady states are attainable. The minimum required information steady state control is discussed below.

A. Non-linearity

Are multiple steady states possible for a single system with fixed inputs? The system would be nonlinearly unstable and vulnerable to strong perturbations. Proper control can reduce the probability of instabilities. Does the system exhibit cyclic or chaotic behavior? Both the economy and chemical reactors can exhibit limiting cycles, resulting in multiple steady states. It is also important to know the property of the lowest steady state. Chemical reactors often have a null steady state or steady states with different properties. In the absence of control, a small perturbation can cause the system to crash to the null state. Restarting the system is slow and difficult. The Great Depression can be characterized as the null state of the U.S. economy in the 1920s and 1930s. Imposing large perturbations can result in severe negative shocks (Shinnar, 1990A).

Complex nonlinear systems have an additional control property. In the absence of control, very small changes can result in different trajectories. Different controls map to different trajectories. Once designed, a control system has a finite number of stable steady states. An improper control can introduce instabilities, causing the system to revert to the null state. In adiabatic chemical reactors, the null state is often stable regardless of control, and the reactor requires special action to be restarted. The ability to take such special actions has to be designed into the system. Chemical reactors can also have stable limiting cycles, which can be complex and chaotic. To evaluate the exact nature of multiple steady states, and of limiting cycles, a proper model is needed. But if the nature of the system is understood, it is possible to deduce by analogy to known linear models whether such nonlinear behavior is likely or not. Observations show that a modern economy has all these features (Shinnar, 1990A).

B. Heat and Mass Balances, Kinetic Driving Forces

A chemical reactor is constrained by heat and mass balances, and by the second law of thermodynamics. Luckily, in a chemical reactor these are easy to compute quite accurately. It is much more difficult to accurately compute the nature of the kinetic reactions, which are too complex for exact mathematical description. This is especially true if, as in oil, there are large numbers of compounds present. This property provides a lumped description of the rate processes. The advantage of a lumped approximate kinetic description over statistical correlation is that statistical models do not easily include constraints. Even an approximate kinetic description with correct heat and mass balances will have built-in constraints. There are equivalent kinetic relations and mass balances in economic systems. Understanding their mechanism is crucial for better partial control.

In process control, signals have the same features and descriptions as real physical flows. Real flows have constraints, signals do not. Real flows count. In economics it is difficult to distinguish between physical and money flows. An example of a money flow is a change in the growth rate of the money supply. Money is a signal, albeit a very useful one. Money flows serve as internal feedback variables that adjust the system. Such internal control variables also play a role in reactor control. The interaction among temperature, heat flows, and kinetic rates provides one such internal control loop, but the reaction engineer knows many others. Good partial control interacts with such internal feedback mechanisms. Most successful attempts at partial control of economic systems use incentives and control actions related to money flows.

In a reactor with complex reactions there is a hierarchy of reactions, variables and flows that require understanding. While there can be a large number of reactions, only a few dominate the heat balance and the performance and stability of the reactor. This is similar to economic systems where different economic activities are not equal. Experience has shown that any complex nonlinear control system with a large number of flows and variables does not exist. If the U.S. is a controllable separate unit which can provide a good sustainable living for all its citizens then there are hierarchies of economic activities. For example, while agriculture contributes only a small percentage to GDP, food production is essential because of national security.

The concept of hierarchy is essential for building proper economic models. The U.S. could import most of its food, but this solution does not guarantee secure sources of supply. Agriculture based on imports is not controllable by the United States. There are additional critical industries. Entertainment provides employment and exports, but cannot stimulate or sustain economic growth. Smaller countries cannot function as independent sub-units. Economic blocks such as the European Union are useful if they implement control through a unified political structure.

It is possible to achieve significant results in partial control with minimal model information. Improved nonlinear steady state and dynamic economic models would focus the discussion on economic policy. These models would include money and physical flows production capacity, natural resources, labor availability, etc. They should be able to describe what happened during the last seventy years. An accurate fit is not required, just a reasonable agreement with major trends observed both in magnitude and time scale. George Dantzig (1977) and Bruce Hannon (1979) have pioneered the first physical steady state model for the energy sector. Constructing such a global, physical economic model for the U.S. would require a cross-disciplinary effort. It could improve the understanding of economic control and policy. Incomplete and approximate models are useful as long as their limitations, assumptions, and level of uncertainty are understood (Shinnar, 1990A). It is also necessary to update models with varying conditions online.

There is one difference between economic systems and reactors. Economic systems involve thinking human beings. They will anticipate what happens and adjust their activities. The control action changes the system. Actually, there is some analogue in chemical reactors. In a complex nonlinear system, such as a catalytic system, there are complex interactions that can reduce or reverse the result of a control action. The use of feedback is still a possibility. Model uncertainty increases. Control engineers develop tools to deal with such systems. Interestingly, the emphasis in the economic control literature is on optimal control, which is unsuitable to systems with large model uncertainties.

C. Timescales and Magnitude of Responses to Various Inputs and Perturbations

It is useful at this point to accurately define inputs and perturbations. An input is a flow or control action that can be intentionally manipulated to control the system. Perturbations are exogenous changes in uncontrolled inputs and changes in the system. Control variables such as money supply or taxes are internal flows generated by the economy. Variables in chemical reactors can be equivalently manipulated and treated as inputs.

Some timescales are surprisingly short. A stock market crash can occur within one day and have a long-lasting impact on the economy. Other relevant timescales in economics are rather long (Shinnar, 1990A).

If there is over capacity, production can quickly respond to increased demand. If new capacity is needed, the timescale is long. In the petrochemical industry construction of a new world-scale plant requires five years. As a result, petrochemical prices and profits have been highly cyclic. A stable system requires excess capacity in critical sectors. Significant excess capacity is not economically sustainable. If growth requires large new investment, the timescales for significant changes can be very large. If a major part of the agricultural sector is to be shut down due to international competition, restarting it could take a long period, possibly a decade. Substituting nuclear or solar energy for half of electricity production would need about twenty years.

Lagged reactions and responses in nonlinear systems have constraints on growth. Crucial resources such as water and energy have natural limits (Shinnar, 1990A). In Israel, if water use exhausts available supply, alternatives such as desalination may be increasingly expensive. Lacking exact estimates, constraints enter into the formulation and construction of the model.

When exposed to a large perturbation, a variable in a reactor can cease to respond to increases in the manipulated variable. This reaction is due to time lags or physical constraints. In such cases, the steady state becomes unstable. The resulting new steady state is the null state. The controls used to maintain steady state equilibrium cannot return reactors to equilibrium. Separate ignition circuitry is required. Agriculture and industrial manufacturing are critical to an economy since they stimulate growth after a collapse.

D. Permissible Control Settings

A serious problem is often neglected when choosing set points with multiple control loops. One can choose any combination of set points in a linear multi-variable system. This condition is not true in a nonlinear system. Some set points will be inconsistent with each other and some combinations of set points may not be attainable or sustainable. This characteristic is important when changing set points. In order to benefit from increases in productivity due to technological change we need to raise the level of economic activity. Everyone’s welfare will increase. This policy would generate consensus for partial control theory.

To achieve this goal we must significantly increase our economic growth rate. Our current level of economic growth is slightly greater than the growth rate of the working age population, adjusted for inflation. Is this goal consistent within the capabilities of current economic systems? Lacking exact models, current information about physical resources and production capabilities is positive. However, as U.S. machine manufacturing declines, the potential of increasing the industrial base decreases. Several domestic industries have a comparative disadvantage in global markets due to increased foreign competition. Thirty years ago the U.S. was the world leader in high-pressure equipment. Today, if one wants to construct a refinery, a large fraction of this machinery is no longer domestically produced.

There are additional questions concerning increasing growth rates. Industrialized economies can attain growth levels achieved during the 1950s and 1960s. The majority of the world's population, residing in Less Developed Countries (LDCs), is unlikely to attain half the per capita income of the United States in the near future. Parity in per capita income of twenty-five percent is overly optimistic for larger LDCs. The technical problem is sustaining such large income differences under free trade. Competitive forces may move the global economy to a new equilibrium with even greater disparity in per capita income. These goals may not be consistent with the economic system even under free trade. Current claims that it is possible to maintain the present standard of living under free trade are subjective. These claims are not based on dynamic or steady state global models.

The sustainability of increased economic activity given a higher level of resource consumption is also a concern. There are limits on fuel and water consumption. Minimal consumer welfare should include adequate food, housing, education and healthcare. Luxury items are not required. Reduction in fuel consumption can be achieved without increasing taxes (Shinnar, 1990B). Sustainable products and renewable energy are more expensive but increases in production efficiency will make their use economically justifiable.

Feedback methods are useful in establishing boundaries for feasible set points and goals. Effective use of feedback involves analysis of constraints, rate processes, and time lags. Obtaining these models is difficult, however, possible and important.

E. Limiting Perturbations to the System

In any control system it is important to limit the magnitude and range of perturbations. No reasonable control can be designed to protect systems from all perturbations. Estimating potential perturbations is a prime consideration in the design of control systems. This concern applies to process control, partial control, and exact control as practiced in the aerospace industry. Currently, there are no mathematical methods available to estimate the maximum perturbations a given control system can handle. These perturbations deal with linear and nonlinear control systems. The problem becomes more critical for nonlinear systems with multiple steady states. A continuing change in one of the inputs can make a given steady state open loop unstable. Transition to a less optimal equilibrium may occur (Shinnar, 1990A).

Stabilizing the steady state with feedback control and a change in inputs may make chosen set points non-permissable. The system will move to a new steady state. Regardless of the control effort, the null state is possible (Shinnar, 1990A).

If the control setting stays permissible, the time delays of the system may not allow rapid perturbations. Only design of a controller in a complex process involves limiting the size of perturbations and their rate of change. In a chemical plant we have many ways to control perturbations. By controlling raw materials and their specifications, perturbations can be eliminated at the source. In difficult control situations tight feed specifications are essential. The other choice is to filter the input by holding tanks. This option prevents sudden shocks and limits the size of perturbations. Reactors do not operate in isolation. They interact with other plant units. Control valves are manipulated over a finite range, limiting the response to any single perturbation. The size and rate of perturbation in any period must be limited. This is required for a successful control of chemical reactors. Control is possible by filtering interactions and limiting their magnitude (Shinnar, 1990A).

F. Choosing Inputs and Variables for Set Points

There are many politically viable control variables. Money flows deal with taxation, selective and global fiscal stimulus, monetary policy, interest rates, subsidies, etc. Legal control deals with import quotas, business restructuring law, or European labor law (Shinnar, 1990A).

A methodology and plan to use potential control handles in an organized way is required. Control distorts the economy. Monetary policy results in biased outcomes. Policy makers choose to move the economy in specific directions. Controls impact social justice. Income taxes are intended to both generate government revenue and to redistribute income. A consumption tax would increase the competitiveness of U.S. industry by leveling the tax content of products. This tax is regressive. The most progressive policy is to increase per-capita income for all groups and recreate the macroeconomic expansion of 1950-1970. Before discussing the relative merits of various control strategies, we turn to important principles for choosing partial control loops (Shinnar, 1990A).

G. Dominance

A variable chosen as an input or the set point should affect reaction rates and impact the thermodynamic equilibrium. This phenomenon is a dominant control variable. A dominant control circuit is any control loop that allows several outputs to remain in an acceptable range. Monetary policy has an impact on many economic activities. Selective taxation can stimulate economic activity in specific sectors and dampen it in others (Shinnar, 1990A). Allowing rapid depreciation in manufacturing increases investment in many activities. Prohibiting depreciation in foreign investment may limit cross-border transfer (Shinnar, 1990B). Unemployment, personal income, growth, and production outputs are good set points with dominant features. Tariffs and quotas are useful to control the trade balance and reduce input perturbations. The focus here is not micro-management but only broad measures having a significant impact on a wide range of activities.

H. Sufficiency

We defined partial control as the attempt to control a large system with many variables and a limited number of control loops. A single loop or two loops may not be sufficient for control. The number of required loops depends on policy goals and experience.

Two to four loops is a good range. When too many loops are used, system control will cease to be partial. When an accurate model is not available, severe problems result due to interactions and the failure to choose a number of internally consistent set points.

The present concept of economic control is a single control loop. The Federal Reserve Board tries to keep the economy stable using one manipulated variable, namely interest rates. While other agencies try to control certain aspects of the economy, only the Fed uses periodic adjustments based on the observation of key economic indicators. Monetary policy is partial control.

The present Fed strategy of relying on interest rates as the main control loop is dominant but not sufficient. Outputs can be maintained in an acceptable range, but control is not achieved. The control actions required by the Federal Reserve to implement monetary policy are significant in magnitude. Since the adoption of this policy, real interest rates are greater than sustainable estimates. Long-run average real interest rates are less than one percent and the expected long-run real return on non-speculative industrial investments is three to four percent. Japanese industry and most U.S. foreign competitors use this latter metric as a benchmark. In the U.S. during the 1950s-1960s, real returns approached ten percent in many industries. In the last 20 years the real return on investments in U.S. industry was closer to four percent. There is no consensus among economists regarding the long-run implications of a control policy based on long-term interest rates in excess of levels warranted by current industrial production.

It has been claimed that high interest rates are not caused by the Fed, but are a result of budget deficits. The data show that nominal interest rates were stable in the so called "golden period" of the 1950's and the 1960's despite higher deficits and inflation in the initial period after the war. Nominal interest rates rose before the U.S. had a deficit. If the goal is to introduce a control strategy to achieve a desired economic environment, the problem of sufficiency must be carefully evaluated. We need to coordinate the use of control variables.

I. Interactions

If more than one control loop is applied, there is dynamic and steady state interaction risk. When two loops are applied, each with two set points, if one input is altered, it will affect the output variables in both set points. This effect holds true for dominant inputs and set points. If the timescale of both loops is similar there is dynamic feedback control interference. It is crucial to choose loops for which the interaction is minimal. The second problem is choosing two set points. The set points could be inconsistent with each other. To prevent this problem, one needs to limit the number of loops. There are highly technical methods to deal with interaction in imperfect models that can be applied to economic control.

There is another less known implication of interactions. If only a single control loop is applied the accuracy and speed of control achieved is limited by stability considerations. A restrictive level of control will make the system unstable. In systems with more than one control loop there is another limitation. Constraints on how tightly the set point variable can be controlled are much stricter. Tight control of one variable creates difficulty if the system is moved to another set point in the other variable. To move the system, the loops must be free in all dimensions.

This property has implications for economic control. The system cannot be adjusted rapidly to a more active state. There may also be difficulties with tight control of inflation or deficits. The acceptable deviation might be larger than what is presently acceptable. The start of the golden economic age of the 1950's and 1960's was accompanied by strong deviations that were later eliminated through economic growth.

V. PARTIAL CONTROL AND THE GLOBAL MARKET

The preceding discussion achieved two goals. First, it provides an economic paradigm. Second, it shows what could be learned from experience about a complex nonlinear system with very modest information.

To achieve the first goal, this paper provides a comprehensive paradigm for dealing with economic growth. There is continuous discussion about the value of a free economy. If the government tries to encourage specific sectors of the economy via tax policy, there is an accusation of free market distortion. Nevertheless, some claim that the government is responsible for economic growth. For example, the Federal Reserve Board is charged with achieving price stability, maximum sustainable output and employment. Any control, such as short-term interest rate policy, distorts the economy and impacts various economic sectors differently.

The second goal of this paper is to show what experience teaches about an exact mathematical model of a complex nonlinear system with very modest information. Learning and modeling relies on feedback. Economists have researched control theory. The focus of research is on optimal control, which requires very reliable models. Optimal control is not suitable for either economic processes or chemical process control. Economic systems are far more complex than even the most complex chemical process. Lessons learned in process control are valuable for economic control if goals are adjusted accordingly. Wassily Leontieff stated that the Japanese used proprietary data to implement economic policy with these methods. Lower levels of raw materials in Japan led to a lower level of control.

One main barrier exists to the implementation of economic control. This barrier is an open global market with free trade in goods or capital. It is helpful to clearly distinguish between the global economy and an open global market. The first is the present state of the world. The second is a policy goal, currently with only U.S. commitment. The reasons why an open global market is not consistent with partial control are as follows:

1. Control requires authority. There is no world government, nor any desire to have one.

2. In large complex systems with limited model information, it is preferable to simplify the system into smaller, clearly defined sub-units. Control systems can be designed to rely on feedback from sub-units and provide supervisory control for the system. This reduces requirements for model information accuracy and is much safer for unstable systems. This reason applies to any chemical plant. The plant manager acts as the central authority. The manager relies on controlling sub-units and following the associated interactions. This suggests a model for the global market based on local trading blocks, such as the European market, with trade block coordination. An independent national economy is required for local partial economic control. If the

national economy is linked with its neighbors, it is not controllable. Trade blocks need political as well as economic integration (Shinnar, 1990B).

3. There is no theory or quantitative model describing the direction of open global trade. The assumption of welfare gains from free global trade are based on eighteenth century ideas. Riccardo's principle of comparative advantage maximizes limited productive capacity. This contradicts Western economic reality where over-capacity and over-production is common. It is unclear if the present standard of living is sustainable in an open global market constrained by limited resources. There is no quantitative model in support of this theory. No model currently predicts the perturbations to the U.S. economy under steady state transition. Related to open market theory is the growing inequality in income distribution in the U.S. and the West. This trend may lead to political instability in democracies. Inequality in income distribution between countries has a lower level of political risk.

Application of the global long-range model leads to different policy outcomes than the free global market model. French agriculture is at a competitive disadvantage in terms of cost structure internationally. International competitors do not require the significant capital investments that a mature industry requires (Shinnar, 1990B). Free global market policy would pressure France to shutter its agricultural capacity. If France did so, similar capacity could not quickly be restored. A reasonable estimate of regenerating French agriculture is 30 years (Shinnar, 1990B). The present surplus of food is because the majority of the global population cannot afford a Western diet. Disregarding population growth, if the third world increased their nutrition to adequate levels, the food surplus and reduced prices would end.

Responsible governments will maintain their essential food supply and agricultural infrastructure. If food becomes increasingly scarce, there is no substitute in consumption. The French cannot consume personal computers (PCs) or information technology for nutrition. The Japanese cannot consume capital goods in place of staples such as rice. Similar arguments apply to all critical industries.

4. Control strategy requires limiting the magnitude and rate of change of perturbations. An open market in goods and capital creates perturbations greater than control capacity. Instead of centralized control, managing the system becomes a game between players. It requires local control strategies of a completely different type. There is no way to enforce the rules of an open market without government subsidies and worldwide interventions. When President Reagan stimulated the economy by cutting taxes, monetary policy and the trade deficit in manufactured goods had an offsetting effect (Shinnar, 1990B). Tax incentives for foreign automobile purchases or overseas plant expansions are similarly moderated. In the case of the U.S., the welfare of corporations' shareholders increases, while the total welfare U.S. workers will decline.

VI. CONCLUSIONS

This paper utilizes analysis traditionally applicable to the study of chemical structures, and finds parallels in economic systems. Generally, partial control of chemical process systems has features similar to those of economic models. More specifically, partial control in chemical reactors has characteristics similar to various aspects of economic models, namely: complexity, non-linearity, and an inability to precisely formulate mathematical models explaining their behavior. Whether in regards to chemical reactors or modeling the economy, it is impractical if not impossible to fully control for all variables. Because of this lack of feasibility for full control, this paper advocates the use of partial control, which involves identifying only key variables that monitor the system.

The paper defines a partial control as an attempt to control a large system with many variables and a limited number of control loops. The paper delineates similarities in partial control in chemical reactors and in economic models. The main barrier for the implementation of economic models is an open global market with free trade in goods and capital. Currently, an open global market is a policy goal that only few countries including the United States adhere to. This paper simplifies the reasons for this lack of implementation to be as follows: control requires authority and there is no world government, an independent national economy is required for local partial economic control, there is no theory or quantitative model describing the direction of open global trade, an open market in goods and capital creates perturbations greater than control capacity. To sum, this paper advocates for applying recent developments in the study of dynamic chemical structures to economic systems.

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