1 INTRODUCTION

What is operational economics?

As suggested in the title of the book, operational economics proposes to replace the proverbial "rational agent" in economic theory by a "manager" trying to deal with everyday brushfire as best as possible using bounded information. This way, we not only can create a verifiable economic theory but also use it to ways to solve dysfunctions experienced in firms, markets and economies. I can perhaps take the credit for coining the term Operational Economics, but the credit for demonstrating how economic theories can be constructed with a managerial perspective goes to Jay Forrester – a control engineer turned social scientist and management professor at MIT who invented the theory building process called system dynamics. Forrester's models evoke an operational approach to understanding economic behavior and managing economic systems. They build on managerial roles not rational agency embedded in mainstream models of economic theory. Forrester's models can, therefore, be easily tied to policies that relate to everyday decisions. His writings provide deep insights that can be effectively applied to managing firms, regions, nations, and the global economic system. This book expands on Forrester's approach to addressing economic problems, and how it calls for rethinking the practice of economics.

System dynamics is a versatile methodology(1) that has been used to integrate existing economic concepts into comprehensive models for providing new insights as demonstrated by Meadows (2), N Forrester (3), Saeed (4, 5), Yamaguchi (6) and many others. Jay Forrester's models however set largely aside existing theory and redefine how economic behavior should be modeled – not as abstract pursuits of rational agents but as actions of real-life managers, which Cyert and Simon (7) have advocated for making economics an empirical science. Forrester's approach was first demonstrated in his book titled Industrial Dynamics (8) and is maintained throughout his subsequent work. His models are based on extensive discourses with the stakeholders in organizations dealing with specific elusive problems. They are built on practice and are coded in a form that attempts to replicate the structure on ground. They lay the foundation of an alternative economics practice that is holistic and intimately tied to how ordinary people working in economic roles make their decisions. They can thus lead to policies that address real roles in an imperfect market.

I have attempted in this book to build on Forrester's approach to economics, embedded both in his published and unpublished work, that views economic organizations as systems of roles that are played by ordinary people making everyday decisions with limited information. The models so created are verifiable and can lead to discovery that modifies role structure for overcoming economic dysfunctions alluded in the existing theory as market failures. Since this approach moves away from the abstract theory that only economist profess to understand, it should be of interest to managers, planners, public officials, system dynamists seeking to model economic problems, and economists seeking reform of the field. Some familiarity with System Dynamics, whether in the context of engineering or managerial and social sciences, is helpful but not essential.

I will construct simple models of Forrester's key premises to support my explanation of his approach to addressing economic agendas. The structure included in these models is an abstract representation of Forrester's models and excludes their details. I have referred to the relevant literature in economics to illustrate how Forrester's approach contrasts with mainstream economics and how it responds at the same time to the wish list of some of the enlightened economists. My several conversations with Jay (face to face and via email) have helped ratify my interpretations. Based on these conversations, I posit that Forrester's models did not come from economic theory, but from his very operations-centered perspective. Since the classical economic thought also arose out of an understanding of everyday role-play, Forrester's models can be related to it. These models seem to call for rethinking the foundations of the so-called normative areas of economics.[1]

I am however not limited to Forrester. I will also construct models of economic problems and metaphorical systems residing in them drawing from fragmented information in literature.

The making of Forrester's operational perspective

Professor Forrester's work focused on realistically representing the actual decision-making structure in organizations for dealing with specific policy issues in his many modeling projects. He placed great emphasis on using experiential information about how people discharge their everyday roles while he set his model boundaries to suit the specific problem behaviors he dealt with (9). The role players in his models work with limited information to balance their everyday acts (10). His models were built from information provided by real world managers and largely ignored theoretical premises of rational choice, marginality and equilibrium growth subsumed in mainstream economics. They albeit addressed key economic issues like the short-run supply

[1] Economics texts place micro- and macro- economic theories that strive to describe the economic system in the positive economics bin. They place developmental and environmental areas of economics that seek value-driven outcomes from policy in the normative economics bin.

dynamics in a firm, the cyclical behavior of an economy, economic stagnation in cities, and environment-economy interaction at the global level, providing new insights that often challenged conventional wisdom.

Forrester's models can be tied to some extent to classical economic theories, which according to Baumol (11) described magnificent dynamics of the free market system. This link to theory may not be deliberate and arises probably because those early theories came also from direct observation of how economic actors went about their everyday business. Indeed, Adam Smith (12) and John Stuart Mill (13) gave copious descriptions of how ordinary people behave while they attributed rational outcomes to the working of the system of roles people played. This important premise of theory was brushed aside when the neoclassical models were formalized into constructs that aggregated individual actions and market dynamics into the concept of rational agency (14), (15).

Forrester's models interestingly seem to fall into widely used partitions of economics. Thus, Industrial Dynamics, which arose from his work with several major production organizations of the country and defined the basic premises of System Dynamics, posits an operational theory of the firm, which is a subset of microeconomics. This operational theory meanders into the System Dynamics National Model, SDNM, creating a seamless integration of actions taken by managers working in firms with macroeconomic behavior. The SDNM thus presents an operational approach to macroeconomics, which is based on everyday decisions of actors and not on the premises of equilibrium growth that assume optimal functioning of markets (16).

Urban Dynamics and World Dynamics, the two volumes that Forrester wrote after Industrial Dynamics, developed from conversations with particular professional groups and ended up presenting operational perspectives on normative areas of economics. Urban Dynamics presents an unconventional economic development model that arose out of Forrester's work with Boston's former mayor John Collins and his colleagues. It ignored the regional and economic development theories of the time (17), (18). Instead, it focused on how infrastructure aging-chains in an open urban economy could lead to stagnation and explored managerial interventions to mitigate that problem (19). World Dynamics posits an alternative approach to environmental economics that grew out of Forrester's dialogue with the Club of Rome – a diverse group of politicians and thinkers whose concern for the future ascended from observation of the out-of-control economic growth. It did not draw from the environmental economics theory of the time that used microeconomics as its key building block and trusted markets to mitigate any impending limits (20). Instead, it showed how resource constraints, endogenous limiting mechanisms and adjustment delays lead to an overshoot and decline behavior over the course of growth. Its aggregate structure was bounded to highlight an impending problem whose awareness did not exist. It was not designed to offer operational policy recommendations for environmental sustainability, although it amply led to further work for creating them (21), (22). An operational perspective was thus clearly the foundation of Forrester's work in the tradition of Mill's premise of practice preceding theory (13), which emerged from his close association with the practitioners.

Industrial Dynamics and System Dynamics National Model: An operational theory of economic behavior

The mainstream economics models represent the behavior of the firm as that of an intelligent agent who knowingly seeks to maximize profit. They explain the behavior of the economy by assuming that firms are functioning optimally, then looking at the interaction between an intelligent aggregate of firms, an intelligent aggregate of households and the autonomous actions of the government. This approach has led to packaging micro- and macro- economics in separate silos that have perpetuated separate text and courses, and specializations in them. Forrester's work seems to have dispensed with these silos by visualizing behavior of both the firm and the economy as manifestations of everyday decisions of ordinary role-players. His Industrial Dynamics is an operational theory of firm, while his System Dynamics National Model is an extension of that theory into understanding macroeconomic behavior. These two models are sketched below separately, but with an eye to highlighting their seamless link.

Industrial Dynamics: An operational theory of the firm

The neoclassical model of firm, which outlines the short-run supply process, overly aggregates the behavior of firm and the market. As a result, the many role players in a firm and their interaction with the market are combined into a rational agent, whose pursuit of profit calls for efforts to balance the marginal cost (MC) and marginal revenue (MR) schedules of the firm as illustrated in Figure 1. This results in production of an optimal quantity Q* that maximizes profit (23). These schedules may vary depending on whether or not a firm operates in a competitive market, and oscillations may occur in this system due to perception delays and lead times (24). This elegant model is far removed both from reality and the narratives of the economic theory, which entail complex role-play by individuals and institutions that do not have knowledge of the whole system. It is albeit widely posited as the theory of firm in microeconomics texts (25), (26), (27).

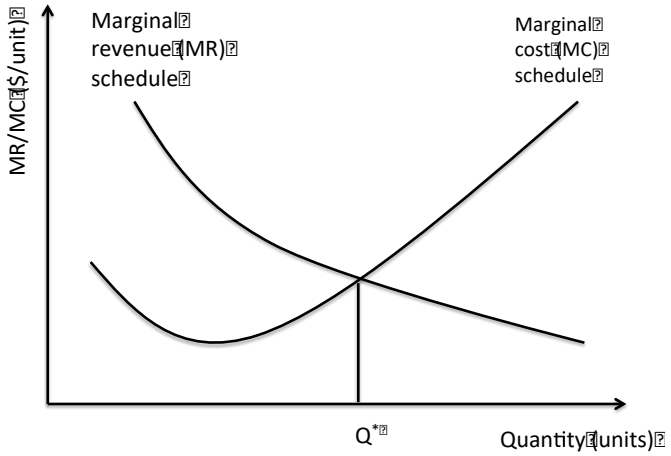

Figure 1 **Neoclassical model of Firm behavior in a competitive market**

Most microeconomics texts also express the dynamics of balancing marginal costs and revenues as a set of differential equations, which Forrester viewed as a step removed from the stock-and-flow structure of systems existing in reality even though the logic of the two representations is interchangeable. He has often stated that differential equations are an un-natural representation of a dynamic system since differentiation process does not exist in human experience. All systems integrate over time.[2] He therefore created a syntax of integration, both for his diagrams and equations, which intuitively corresponds to how systems change over time (5). This representation has become the language of system dynamics, although many system dynamists (this author included) often present their models as systems of differential equations in the interest of facilitating communication with a large audience.

In Forrester's model of a firm, the decisions to produce, add or lay off capacity (workers, machines), and order raw materials and parts, are made by multiple managers working in their bounded-rational roles as envisaged by (28). Managers working with limited information try to adjust the number of machines, inventory, and workforce to be able to clear their backlog of orders. Their actions are motivated by their own delivery delay conditions more than by price, which in default is assumed as given – a reasonable assumption for a price-taking firm dealing with the short run. This system seeks a dynamic equilibrium but may never arrive at it. The adjustment processes affecting capacity utilization, workforce and machines create major negative feedback loops that result in instability as shown in the simulation of Figure 3.

Forrester advocates using the same building blocks for modeling the behavior of a market. (8). He, however, excludes the market dynamics from his analysis of the firm, although he portrays the short-run supply system as a supply chain that cascades managerial actions in multiple firms. Such cascading can amplify instabilities that we now call the bullwhip effect (29). He extensively tests the dynamic behavior of the supply system by subjecting it to a variety of demand profiles with a focus on improving operations within the firm. He takes the market conditions as given and does not get into the impossible task of seeking policies for making them perfect. Instead, he identifies decision patterns that lead to dysfunctional outcomes and is able to prescribe policy changes addressed to managers to mitigate them.

Another point to note is that Forrester does not replicate the solution regimes of conventional numerical methods that often express a simulated solution to a system of differential equations as an exhaustive set of outcomes in a given parameter space. Instead, he provides an explanation of the behavior of his models as the outcome of the feedback loops driving it, thus creating an understanding of the structure-behavior link valid for most plausible parameter sets. Furthermore, since compensating feedback loops create insensitivity to parameters representing tastes and preferences (9), he places greater emphasis on precisely representing system structure than on accurately estimating its parameters. This is almost opposite of the requirements of

[2] See the transcript of a conversation with Forrester, available at:

https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3504274 ; last accessed: January 22, 2023

econometrics, which has been the key modeling tool of mainstream economics (30). In a memo written in 1956, he states:

"I would prefer a structure in which I had confidence using intuitively estimated coefficients rather than an unlikely structure and functional relationships for which coefficients could be derived accurately from statistical data." (31)

Forrester's operational perspective yields an alternative model of firm that can be used for creating policies enacted by ordinary managers to improve performance instead of seeking to establish an environment for the efficient working of a hypothetical rational agent. His solution regime calls for understanding the endogenous causes of observed behavior that often point to corrective operational policies. His approach promises to transform an abstract theory of firm into a model useful to management. If Forrester's model of production is extended to include market responses, costs and prices, it can lead to the creation of an operational microeconomic theory in which ordinary role players and market together create optimal outcomes. These role players can also have a wide range of personalities and personal preferences creating a variety of parameter sets driving the feedback system they work in. Yet, the behavioral patterns created by their actions will not change much due to the compensating nature of the coupled feedbacks that ameliorate changes in adjustment rates fueled by each.

System Dynamics National Model (SDNM): Industrial Dynamics segue into Macroeconomics

Most texts on macroeconomics start with an exposition of historical time series representing GDP, GDP growth rates, prices, and unemployment rates. They then discuss the composition of national accounts and culminate into abstract models describing multiplier and acceleration principles, business cycle, the velocity of money, and government interventions in terms of expenditure, fiscal instruments, and monetary controls, without ever connecting those models to the historical trends the texts begin with. Firm-level actions are assumed to be optimal throughout this analysis (32), (33).

The term "economic cycle" has sometimes been used interchangeably with business cycle, but the former refers to a wide range of periodic ups and downs superimposed on growth history, while the latter usually implies a 5–7-year cyclical trend observed in market economies. The business cycle has traditionally been attributed to investment dynamics (34), although Low (35) showed that capital formation lead times and capital output ratios existing in reality would in fact generate cycles of much longer periodicity. The real business cycle theory advanced by Lucas (36) attempted to explain business cycles by attributing them to the rational responses of the economic actors to external events. Thus, each business cycle could have a different explanation and a different periodicity. Forrester on the other hand tied the cycles of multiple periodicities experienced in the market economies to specific firm-level patterns of decisions in his unpublished System Dynamics National Model (SDNM).

Given the SDNM project had an explicit objective of understanding the behavior of a market economy, Forrester could have built on the existing macro- and micro- economic theories and relaxed their limiting assumptions to make his model realistic. He instead built on the production process described in Industrial Dynamics. The behavior of his model succinctly explained the

complex historical time patterns combining cycles of multiple periodicities given at the start of the macroeconomic texts in terms of every day managerial actions. In addition to the 5–7-year business cycle, he expounded also on two other distinct periodicities - an 18–25-year Kuznets cycle and a 50–60-year Kondratieff cycle or long wave, observed in the historical data of free market economies. Few other theories explain such long cycles and growth trends experienced over them have often been attributed to good economic management and good governance, while unfortunate events are blamed for declines (37), (38).

Some of the findings of Forrester's national modeling project are documented in Mass (39), Graham and Senge (40) and a number of internal memoranda and Ph.D. theses listed in the system dynamics literature archive available from the System Dynamics Society. Of particular interest among these memoranda are "Introduction to the System Dynamics National Model structure" by Graham (41), "Capital formation and the long wave in economic activity" by Low and Mass (42), and "The economic long wave: theory and evidence" by Sterman (43). Additionally, doctoral dissertations by Mass (44), Low (45), Runge (46), Richmond (47), Senge (48) and Sterman (49) address various aspects of SDNM. The findings of this extensive research led to unique causal explanations of endogenously generated short- and long- term economic cycles.

The SDNM could generate behavior encompassing multiple modes created by different segments of its complex structure representing managerial role-play. Since it involved oversight from a number of MIT economists, the effects of price, liquidity and marginal costs and revenues did get subsumed in its decision structure, although they were not critical to its unique explanations of the complex economic history of free market economies (43). Complex behavior can however be decomposed into its simpler components, and simple models constructed to understand each component in our theory building effort (50). I will therefore outline two parsimonious models, based on public documents on the National Model, that I have built in my attempt to interpret separate slices of Forrester's operational theory underlying cyclical patterns of different periodicities. The first generates Business and Kuznets cycles with appropriate parameter sets; the second replicates the long wave.

Notwithstanding the disequilibrium behavior under study, a hypothetical steady state is a point of reference in these models. This steady state represents a dynamic equilibrium created by an internally consistent set of parameters for a homeostasis sought by the system but never achieved. Model equilibrium is disturbed by changing a single parameter to invoke the search for the homeostasis, which results in the disequilibrium pattern of interest that is completely endogenously generated and explained entirely in terms of the structure of the respective model.

Supply line delays creating Business and Kuznets cycles

The 5–7-year business cycle in the National Model was attributed to supply line instability arising out of workforce adjustment process responding to changes in demand. The 18–25-year Kuznets cycle is explained as supply line instability arising from the capital plant adjustment process. Production must not only fulfill the perceived stream of demand, it must also maintain an appropriate level of inventory that is able to cover unanticipated shocks. Additionally, an appropriate backlog of orders must be maintained to allow the operating businesses to plan their production. Thus, desired production is computed as average shipments modified by the

adjustment rates of inventory and backlog discrepancies. Desired backlog is determined by average production and desired inventory by average shipments. The demand side of the economy is exogenous to this simple model, and it is separated from supply side by inventory and backlog.

When the production factor is workers, production will depend on workforce, overtime (capacity utilization) and labor productivity, while shipments depend on the backlog of orders and the availability of inventory. Factor orders translate into hire/fire, which is driven by attrition (factor retirement) and the discrepancy between existing workforce (factor) and desired workforce (desired factor) merited by the desired production volume, duly adjusted by the in-process hires (factor on order).

When this common structure applied to capital formation practices, the factor adjustment lead times are of the order of 3-5 years, while the average life of factor is 15-20 years. In addition, the capacity utilization regime is a bit different. While it is not possible to keep workforce completely idle, capital utilization can potentially go to zero. The capital adjustment practices lead to a cyclical trend with a periodicity of about 25 years. The delays in the expansion process lead to overexpansion of the capital. The subsequent piling up of inventories and depletion of backlog result in an extended neglect of investment, which creates a recession much longer and deeper than in a business cycle.

When the two periodicities are superimposed, business cycles will show longer periods of growth than decline over the upturn of a Kuznets cycle and shorter periods of growth than decline over its downturn, which is also borne out by experience.

Investment goods self-ordering creating Kondratieff cycle or long wave

A periodicity of 50-60 years observed by Nikolas Kondratieff was explained by SDNM as a function of the interaction between consumption goods and investment goods production sectors. When the consumption goods sector wants to create additional plant and equipment, it places orders for them on the investment goods sector. When the investment goods sector has orders beyond its capacity to deliver, it must expand its own capacity to be able to fill capital orders of the consumption goods sector. Thus, it places additional orders to produce investment goods on itself that Forrester termed self-ordering.

The consumption goods capital formation is limited by investment goods production, which is apportioned between consumption goods capital formation and investment goods capital formation depending on their respective amounts on order. The desired capital in the investment goods sector depends on desired investment goods production, which is a function of the summation of both investment goods on order for consumption goods production and those for investment goods production. However, unlike the consumption goods production sector, the investment goods on order represent both the investment goods sector’s order backlog and its capital supply line. Thus, it leads to stepping up self-orders by the investment goods sector instead of adjusting them down, creating a reinforcing loop. Last, capital orders in the investment goods sector are driven both by the investment needs of the consumption goods sector as well as its own needs.

The delays in delivery create over-ordering by the consumption goods sector. Self-ordering by

the capital goods sector, which must ration deliveries to the consumption goods sector until the desired production capacity for capital goods has been achieved, further increases this over-ordering. Once the investment goods sector has achieved its desired production capacity, its self-orders vanish, but its production capacity is now enough to cater for both its self-orders and those from the consumption goods sector. This speeds-up clearance of the backlog of orders from the consumption goods sector, which in turn scales down its orders. The drop in orders leads to reduction first of capacity utilization and then investment in the capital goods sector, which spirals into creating a sustained downturn. It should be noted that this simple model attempts only to highlight Forrester's explanation of the long wave. It excludes other correcting feedbacks included in SDNM that should reduce the amplitude of the cycle. It also excludes endogenous growth and decline processes residing in the impact of worker layoffs from reduced capacity utilization on household income and demand, which should increase the amplitude.

Forrester's national model explained historically recorded macroeconomic patterns in terms of the actions of managers working in their everyday roles. It stayed away from the variations on abstract equilibrium growth concepts that the cycles have been attributed to in mainstream macroeconomics. It calls for a rethinking of the models of macroeconomics tying them to everyday actions of the people managing the firms and other institutions in the economy instead of assuming optimal performance at the institutional level (51). It, therefore, presents a seamless model of the economy linking microstructure to macro-behavior that creates an opportunity for designing operational interventions for economic management.

Modeling projects visiting normative economic domains

Forrester's research group, between the time he published Industrial Dynamics and the beginning of SDNM project, undertook two other significant studies. Forrester has often attributed them to happenstance. The first was initiated by his chance encounter with the former Mayor of Boston, John Collins; the second arose from his interaction with the Club of Rome. These projects led Forrester to visit normative domains of economics. His books Urban Dynamics and World Dynamics that arose out of these projects posit alternative approaches to development and environmental economics that challenge mainstream ideas which will be built upon in this book.

Urban Dynamics as alternative approach to development economics

Forrester built his Urban Dynamics model not theoretical premises but from working with city managers. And, following his principle of representing the stocks and flows in the model as they exist in reality, he describes a physical system consisting or infrastructure aging chains and worker mobility process with flexible worker and capital flows and capacity constraints that effect different infrastructure aging chains differently.

Since workforce can change through migration while capital investment can also flow in from and out to other regions in contemporary open economies (52), He also assumes higher rates of mobility for the managers/professionals and labor than for the underemployed, which is consistent with the concept of poverty traps in the developing countries (53). Forrester's model

tends towards an end equilibrium which is characterized by stagnating businesses, a lack of entrepreneurial activity, high unemployment, and dilapidated housing - conditions pervasive in the developing country economies before economic development efforts began, as well as in mature urban areas in the industrialized countries over the mid-twentieth century.

World Dynamics as alternative environmental economics framework

The microeconomic foundation of the mainstream environmental economics texts is illustrated in Figure 2. It personifies the society faced with environmental repercussions of its decisions as an intelligent agent who is now environmentally conscious and cognizant of the their marginal damage and marginal control cost schedules, which they balance to produce an optimal quantity Q* at an optimal cost C* (54), (55).

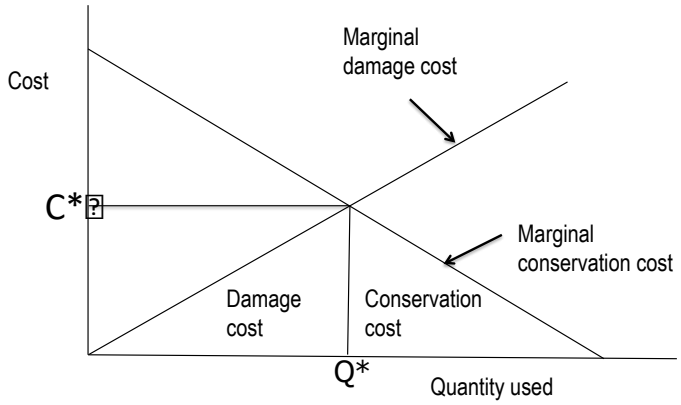

Figure 2 Microeconomic foundations of environmental analyses in environmental economics texts

Multiple firms operating in the economy can also recognize these damage and conservation cost schedules through bargaining when decisions of one firm affect the others (56), and can end up following these schedules when negotiation costs are low. When private costs can still be externalized, the socially optimal quantity will fall short of privately optimal quantity, but governments can shift these schedules through fiscal means to correct the problem (57). The optimal quantity produced in this model may have no relationship with sustainable quantity, as the marginal cost schedules may not capture the long-term changes in resource stocks created by an imbalance between use and regeneration. Thus, a socially optimal quantity achieved through Pigou taxation may still lead to a tragedy of the commons (58).

In reality, this aggregate model is not only unable to lead to policies for sustainability; it calls also for measurements that are almost impossible. Forrester's World Dynamics model on the other hand not only subsumes the systemic growth and limitation concepts spelled out in classical economics, it extends them also to subsume the environmental constraints. It therefore provides an alternative foundation for environmental economics.

Forrester's world dynamics model, although built from the informed concerns of members of the Club of Rome, not from classical economics, ties into latter through their common principle of building theory from practice. It also challenges the relevance of the microeconomics foundation of environmental economics that is unable to deal with tipping points. Unfortunately, environmental economics texts have not moved away from this arbitrary foundation, which the

discipline adopted in its infancy, even though it provides little help in addressing the complex environmental problems of today. Entrenched in the models of these texts, economists have continued to debate if the pursuit of economic efficiency will lead to adoption of technologies that limit emissions and mitigate the already created accumulations, which might be a tall order for the market to deliver.

Summary

Contemporary economic theory is built around the abstract concept of rational agency that aggregates multiple and iterative managerial decisions and their outcomes into the concept of rational agency that removes it form how the economy works in reality. The theory this loses a point of reference for its verification, creating a runaway train that has become more and more abstract over time. This theory cannot provide guidance for the actual role players in real world organizations to modify their role-play for improving the behavior of the organizations they manage

Even though simplified cobweb theory to argue for his theory of rational expectation, its inferences cannot be easily extended to real-life complex systems. Rational outcomes are created in reality by the iterative working of the whole system. Rationality is not embedded in the abstract roles of the agents representing the system as implied in mathematical models of economic theory. Managerial actions are information-bound and depend on a multiplicity of factors internal to the firm or the sector in an economy. They create outcomes driving further action. This iterative process can create both functional and dysfunctional outcomes as borne out by experience.

The practice of economics has since subsumed many revisionist ideas including institutional and behavioral factors (59), (60), which have the potential to create an evolutionary change in the field. These innovations incrementally modify existing models by subsuming learning, belief-related factors, rationality bounds and irrational psychological criteria into the actions of a rational agent. Richmond (61) emphasized operational thinking as a critical skill for all modeling efforts aiming at policy design, while Radzicki (62) advocated using system dynamics for representing institutional and behavioral factors in economic models. These propositions are largely ignored in the mainstream practice of economics. A disruptive change in economics that replaces its rational agents with real role players is needed which this book explores.

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