

The Interconnection Between Natural Sciences and Economic Systems

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ABSTRACT

Adam Smith's inquiry into the nature of wealth and the reasons for its differences is just as pertinent today as it was when he posed it. Smith, the father of economics, could not imagine the substantial advances made in diverse fields such as mathematics, astronomy, biology, and geology in unraveling the variety and complexities of the side and variability of wealth among societies. The wealth of nations is fabricated by the great endowment of the land with combination of resources, complemented with a certain development of the techniques to exploit and combine them and, it is the economic systems structured on prior conditions.

INTRODUCTION

Understanding the nature of an economic system, its structure and consequential aggregate behaviors, can help answering the question by making use of knowledge from other fields of science; knowledge that in its infancy was fundamental for an interrelated and broadly construed study of wealth and its differences. It is a goal of the author to renew the search for a wealth of nations theory and bring it broadly back to the economist domain. Concomitantly, it is hoped to legitimize the generalization of the folklore of scientific considered notions/natural systems to systems and entities that supposedly fall in the social scientific domain. It is argued that understanding economic phenomena can only be attained by considering those systems as interdependent and interacting entities with environmental systems and that inflation and crises are states of such systems (Aronson et al., 2006; Hasan, 2016; Kutasi, 2022; Malo Larrea et al., 2024; Richardson, 2023; Spash, 2015). For followers of Claude Bernard, the circumstances surrounding his life drastically changed thereafter. His thick book entitled *Introduction à l'étude de la médecine expérimentale* (1865), whereas the first part deals with the method of the experimental sciences and the last part mostly with technical aspects for experimentation, is the key reference for the science of physiology and inspired considerably Limoges' methodological situation. It contains some of the most famous insights about the scientific approach and the principles of the science of life. Bernard has concerned about the legitimacy and peculiarities of a science which object is of qualitative nature. The present author hopes that simply by displaying allegories and metaphors, economic systems can possibly be connected to those of the natural sciences in proof of their natural status.

LITERATURE REVIEW

The process of economic development accompanies major changes in all facets of economic systems; the structure of an economy, its institutions, and policies can change drastically. These changes may feed back and generate additional innovations and developments in an increasing returns process, in which case it is called economic growth. However, not all such changes will lead to enduring changes, or growth. A fundamental understanding of the timing, pacing and nature of change, its driving forces and its emergent properties can be approached by dialectance: a search after invariants and symmetries or invariance under changes in the description of a system.

Natural systems composed of relatively simple and largely passive building blocks show changes in coherent structures over time and/or space. City development, urban sprawl and the evolution of industrial sectors are examples in which economic systems composed of economic agents, such as people, firms and governments, structural changes can be caused by a finite number of possible building blocks. Resources for economic production include materials, knowledge, institutions, space and work, which will be treated as initial conditions without exploring their source. Resources and capacities determine the path and outcome of innovation waves and shapeshifting such as industrial quarters or neighborhood gentrification as demonstrated previously by the development of cities or industrial systems.

This analysis emphasizes how the occurrence of industry and economic development in cities, and hence within and across countries, is determined by the gradual accumulation of hard and soft technological knowledge, institutions, infrastructure, and overwhelming returns to scale. Economic models contain explanatory concepts and design principles necessary for building simulations of innovation waves and endogenous economic growth. Expectations of totally symmetric growth of an economic quantity far nesths empirical reality. Detrended cross correlations of growth rates reveal that symmetry holds only over limited time frames. This morphospace of time scales and symmetry breaks economic perspectives at a mere descriptive level. Less symmetric parameters reflect endogenous processes shaping economic symmetry. Economics is mainly concerned with 'simplistic' theorizing, centered upon constrained optimization; this is a view that many economists might regard as justified. However, it is argued that all parts of the economy are inhabited by complex adaptive systems operating in complicated historical contexts and that this should be acknowledged at the core of economic analysis. That this has not been done in the discipline of economics, and certainly in the mainstream part of it, is part of the disappointment with post-1945 economic theory. Yet there is also satisfaction in being able to judge from the current vantage point the very great strengths of modern economics and in recognizing that complex systems science is a domain of inquiry whose potential has yet to be exploited comprehensively. Consider some of the challenges that exist.

The production function construct has been used in economics for many decades, providing what has been a highly abstract representation of the forms of these networks that are existing in complex adaptive systems such as firms. This is illustrated with reference to a Ricardian example, and the view is taken that modern knowledge of economics provides a sound basis for reconstruction of the theory of firm and agency wide behavior as regards its motivation with respect to transaction cost efficiency. The modeling of complex adaptive systems in terms of agents and of coarse-graining has only very recently been applied to modeling the economy. However, there are already grounds for optimism that it might be possible to avoid some of the failures that have beset the modeling of the firm. Pace of integration and cooperation is markedly enhanced.

The macroeconomics of John Maynard Keynes is revisited with a view to highlighting how some economists in earlier times were able to provide powerful economic analysis that was based on intuitions that we can now classify as belonging to complex systems perspective on the economy. It is prima facie likely that opportunity existed for others of this ilk during the early post-war decades, notably with respect to Charles F. Roos and the Cowles Foundation. Examination of reasons why this did not outcome forms a major part of the analysis. Amongst the possibilities, explicit reasoners have such a cogent rationality that it is reasonably expected than even tacit agents will not differ in expectation about basing decisions. The resultant narrowing of the equilibrium concept to a unique price and quantity, alongside attractions of the log-normal assumption for price dispersion, is more than enough to foreclose

lines of inquiry that might otherwise have been fruitful. The Natural Sciences encompass the disciplines of Biology, Chemistry, Earth Science, Mathematics, and Physics, which involve the observation and analysis of the natural environment and its accompanying interactions. Their insights extend to the construction of stable economic systems and the modeling of resource management and sustainability. In contrast, Economics focuses on information, speculation, and communication, employing the language of math and statistics to represent intangible information processing abilities articulated via symbols. While the Natural Sciences are concerned with physical and biological phenomena, Economics focuses on systems of interactions between agents and the mutual influences between systems and agents. Given the similarities in reasoning processes and notation of the two disciplines, their use distinct tools and modeling approaches, it is important to find methodologies and theoretical frameworks based on the Natural Sciences that can be applied to the construction of economic models for both strategic and tactical decision-making. The exploration-oriented dynamical models originating from Ecology seem particularly promising to further this goal.

Economic systems are representations of knowledge, information processing, and understanding. They are partial representations and, as such, each economic researcher temporally models cover only aspects pertinent for the issues being addressed. They are also tacitly constructed, for neither the development nor the above-mentioned reassessments arise from a conscious modeling effort (Avery & Francis, 2014; Dolfsma & Foster, 1999; Samuels, 1988; Slade-Caffarel, 2019). They intuitively evolve, spontaneously restructuring, along with evolving more fundamental understanding, either analytically or numerically. In turn, this more fundamental layer of understanding is neither uniform nor equally distributed among specialists in different parts of the models. As a consequence, the share of knowledge going into any set of economic system representations is heterogeneous and typically incomplete, responsible for their scarcity and fragility. All forms of economic system representations originate from physical analogies and then surf the various kinds of symmetries obeyed by the reality they were designed to capture. For decades, all classes of economic models have shared the same ontology upon which the modeling of economic interactions and structure was based.

METHODOLOGY

This paper is based on theoretical analysis. Its methodological approach draws upon conceptual frameworks that intersect natural sciences and economic systems, aiming to elucidate their interdependent dynamics. Rather than relying on empirical or statistical datasets, the study employs comparative theoretical synthesis—analyzing core concepts, models, and structures across disciplines such as ecology, thermodynamics, systems theory, and economics.

The goal is to build a coherent interdisciplinary foundation by identifying analogies and structural symmetries between natural and socio-economic systems. In doing so, the paper integrates scientific reasoning drawn from the natural sciences (e.g., energy cycles, ecosystem feedbacks, and

biological resilience) into economic discourse. Key methodological tools include:

1. Cross-disciplinary literature review and conceptual modeling;
2. The use of analogical reasoning and metaphor to map natural phenomena onto economic behaviors;
3. Normative theoretical interpretation to evaluate policy relevance and sustainability;
4. Dialectical analysis of invariance and systemic feedback loops as they appear in both natural and economic systems.

The study refrains from empirical simulation or econometric testing; instead, it proposes a paradigm that seeks to generalize patterns from natural sciences to economics, offering a new theoretical lens to interpret complex economic phenomena.

RESEARCH RESULT

Economic systems are complex structures consisting of actors (people, firms, the state) exchanging goods (tangible and intangible) and services in the context of a defined stock-flow equilibrium. The interactions between actors produce flows corresponding to income and expenditure streams and changes of net wealth associated with losses of goods under the form of wear and tear, consumption, unused gold stocks, etc. All exchanges are recurring, which means that income can be sent to banks, capital accumulation generates wealth, etc.

Since its inception, economic science has mostly been used as a political tool, to defend the construction of empires, to justify colonization and slavery, or to defend mercantilism, protectionist tariffs, and the absolute necessity for balance data. When used as a tool to defend the proposed organization of society, opposed to those in place, it has shown its weaknesses to answer theory questions. The uncovering of its consistency limits the study of marginalism, complexity, chaos theory, and capital accumulation dynamics, and generates the impossibility result regarding the need to impose an economic policy.

There is plenty of room for inquiry regarding the relationship between social organization and the future of humanity. Classical science looks at the economy behind a narrow lens from the individual maximizing utility and solving syntheses of equations representing partial equilibrium on markets. People, their wealth and income, as well as producer firms investing and producing goods and services, are represented by point masses in nD space. There is no room for economic shocks or environmental changes -the simulation horizon is usually within some decades- and no interaction with other systems whatsoever. Despite the long-standing recognition of the crucial role technology plays as a determinant of societies' relative economic development, scientific inquiry into the economics of technological change was born only rather recently, notwithstanding isolated earlier contributions. Four large classes of contributors to the economic analysis of technological change can be distinguished: growth theorists; organization theorists; industrial organizationists; and institutional economists (Beckerman, 2000; Harvey & Clark, 1965; Köhn, 2017; Lawson, 2005, 2006). Now-in-a-days, interest in the

effects of technology on economic performance is more widely spread, and major questions are being addressed also by mainstream economists. Technological change is becoming an essential topic in economics journals and at major conferences. It is admitted to be an essential factor of economic growth and is being studied, as such, by new growth theorists. Many studies focus on the firms' technological strategies, notably their R&D exertion, and include a particularly rich section on the interaction between R&D, technological change and market structures. Technological change is at the center of attention in new industrial organization economics and is being examined by several (institutional) economists, who are most interested in the effects of the political system on innovation. In terms of its motivations or applications, however, the work of these groups is relatively less evident.

The dynamic interconnections between the natural sciences and the economics of living standards are means of augmenting knowledge, discovering, understanding and applying new facts and principles about the physical world, and transferring and distributing new or adapted knowledge to firms and workers. The historical systems of science, technology and economy of countries and regions are long-term, co-evolving complex systems, embodying a variety of human populations, linguistic and cultural groups, institutions and rules, infrastructures and structures, and long-lasting and path-dependent properties. The socio-economic and technological growth regime of living standards of countries may change across time and space, depending on the exogenous shocks of scientific and technological breakthroughs and institutions. The dynamics of science, technology and economic growth walk on pathways the rules and institutions of which may differ considerably among regions. Moreover, the incidental complexities produced by apparently random noise on the historical pathways of the growing countries and regions could greatly differ due to different kinds of shocks and/or rule-based metrics of growth.

As mentioned above, the second generation of modeling efforts of some economic systems sometimes produced complex simulations that shared key features with models built by analysts of the natural sciences. At the same time, a large body of theorizing claimed at least partial successes in more intelligent agent-based modeling that in some respects worked as expected but did not possess the "well-posed" character of ecological modeling, composite statistical time-series analyses, or many sorts of theoretical physics modeling. There, economic systems yielded artifactual properties through naïve numerical aggregations of non-linear deterministic systems with lots of positive and negative feedbacks. In the absence of overarching knowledge that could be expressed in a coherent language, those models could not be assessed, let alone verified. In the case of aggregate modeling, the non-uniqueness of the statistical model had to be corrected (according to the trade-offs outlined above), which parameterization was discovered in the context of the modeling process itself, and these insights could not easily be encoded into a general language. Because all attempts at building mathematical expressions seemed to end with non-robust *ex ante* conclusions, claims of comparative or functional stability risks

misclassifying other sorts of logic, i.e. tending to designate some “less relevant” trajectories at the basis for more coherent or less volatile fluctuations.

Nevertheless, the modeling processes of Lowe and Solow started somewhere else, after either experimental observations and then a theoretical search for parameterized models acted into the dynamics or exogenously prescribed processes. The intertwined sequence of observations, conjectures and decisions is a prime field for some sort of interdisciplinarity. Basically the same modeling behavior seem to help natural scientists and economists to analyze boundedly complex systems, even resulting unintentionally in fruitful intersections, triggering the emergence of new understanding and analyses. To stimulate such a collision of expertise or strategies (arguably toward a form of jointly “second generation” research) where and how do boundaries between disciplines in the sense of incommensurable and encapsulated paradigms occur and how could they be breached? What would constitute a problem addressed? Would it be enough to analyze only cases where a common language is achievable at the symbolic or ‘mathematical’ level (defined widely to include statistical and computational descriptors)? Or are there other forms of interaction that could be studied? Would incommensurabilities at some aspect of a research process preclude some sort of interdisciplinary collaboration or some potential access to the respective discipline by description through the other?

Natural resource economics is the study of how natural resources are developed and allocated in human economies. Natural resources are stocks of economically useful commodities that occur in the natural environment and are not tormented through human industry. An economics perspective separates the society in which resources function, for merely to study them is bad enough. The ‘biophysical and economic determination of resource’ interaction is an espoused model of such a variety of thoughts, and suggests some impossible properties for natural resources. Nature is the zero-cost producer leaving the economist with a difficult concept and sole task of demand specification; resources are stocks in space independent of use a-posteriori to the process; co-ordinate unit time before and/or after use must be specified in a model for economic estimation to take place; the infinite dispersion of only incompletely substitutable inputs cannot be matters of finite process (Challoumis, 2023b, 2024a). They admit agents with an infinitely speculative arbitrage ratio who seek out the best opportunities, and monopolists however weighted, wish infinite economic power; and finally the most sacred and influential calculus, that is, functions may wax convex. Natural resources are defined as stocks of material in the natural environment that are both scarce and economically useful in production or consumption. Importantly, in the economics sense, they are often defined independently of and aside from a resource’s economic use as a resource. Natural resources comprise a broad range of environmental input stocks. Broadly speaking, the definition includes an increasing variety of renewable resources; commonly, only the depleting stocks of metals, minerals, energetic fuels, freshwater aquifers, fossil aquifers, etc. accrue resource attention.

Ecosystem services, the benefits that individuals and society derive from a functioning ecology, are undermined by human-environment interactions. Ecosystems provide goods directly used by society, such as timber and food, but they also provide myriad benefits, termed "ecosystem services." Changes in ecosystem structure and functioning alter the quantity and quality of ecosystem services, which, in turn, impact human welfare (Challoumis, 2018, 2021, 2024c). Ecosystem services are currently irreplaceable and inelastic with respect to price, purposing a valuation approach. A wide array of methods has been proposed to value ecosystem services, but a comprehensive economic consideration remains elusive. If ecosystem services are economically valuable, then a challenge is to identify the link between ecosystem services and individual quality of life. This essay reviews the consideration to date of this fundamental question in economics, outlines a promising approach to expand research in this area, and considers how policy might evolve to integrate this knowledge into the economy.

People do not characterize ecosystem services in the same way as economists. The majority of eco-programs rely on specialized messages that describe environmental benefits as avoided negative external effects often framed in dollar terms. Framed this way, environmental services are difficult to comprehend. Complexity aside, disinterestedness is an equally troubling issue. A natural resource of concern may be cast as *de facto* common property. Concern for other people's values or for future generations' welfare suggests an exploration attitude. Nevertheless, even within the consumer choice foundation, the use of subjective risk, ambiguity, and time-incongruency within a stochastic dynamic framework offer a diverse and promising frontier.

DISCUSSION

This paper seeks to create a new conceptual framework to explain the interdependence of natural sciences and economic systems. In today's world, which is more interconnected than ever before, it is vital to take a more comprehensive, systemic view of human and social dynamics. The extension of classical Newtonian mechanics-driven construct of reductionism and determinism to the study of economies is simply wrong.

Overly prescriptive, dogmatic approaches to knowledge may hinder scientific progress on complex issues. A more interdisciplinary stance is necessary, viewing the economy as a perfectly legitimate object of study across the entire spectrum of the evolving and yet universal notions of a complex adaptive system. Indeed, there is a hazard of theories in social dynamics diverging, as they lack common scales, concepts and methodology. Linking across disciplines, notably across time and spatial scales in a nested, delicate fashion, is particularly daunting. In-depth respective knowledge of the realms and systems, often in non-symmetrical formats, is a prerequisite for productive cross-fertilization. Deeply held conceptions, ideas and paradigms may also stand as barriers to fruitful exchanges between fields. Fundamental matters of a theoretical, moral, social, political and ideological nature arise. Nevertheless, interactive systemic evolution, comprising both natural and socio-economic

agents, is the challenge facing humanity. Risk and fate must be embraced, not avoided. If these challenges are to be comprehensively studied and understood, it is eminently desirable to attempt to create paradigms able to embrace complexity science across disciplinary boundaries. The interplay between natural sciences and economic systems ought to be understood from afar, with a basic and general view. Partly as a defense against eye-glazing abstractions, the Geography of Innovation is chosen as a most timely theme within which to study interdependencies between natural sciences and economic dynamics.

CONCLUSIONS AND RECOMMENDATIONS

This paper presents a conceptual model describing the medium and long-term co-evolution of natural and socio-economic subsystems of Earth. An economy is viewed as an out-of-equilibrium dissipative structure that can only be maintained with a flow of energy and matter. The distinctive approach emphasized here consists in capturing the economic impact of natural ecosystems being depleted and destroyed by human activities via a pinch of thermodynamic potentials. This viewpoint allows the full-blown integration of a limited quantity of primary resources into a non-linear macrodynamics that is stock-flow consistent both in terms of matter-energy as well as economic transactions; the inclusion of natural and forced recycling; the inclusion of a friction term which reflects the impossibility of producing goods and services in high metabolising intensity without exuding energy and matter wastes; the computation of the anthropically produced entropy as a function of intensity and friction. Analysis and numerical computations confirm the role played by intensity and friction as key factors for sustainability.

A very large part of the literature addressing integration of physical, ecological and economic systems is based on dynamic modelling approaches such as ODEs and PDEs. Given their computational complexity and potential lack of robustness, such models should be used cautiously (Challoumis, 2023a, 2024b, 2024d). Consequently, there was a clear need for models requiring only minimal numerical resources in order to produce socio-economic and environmental data relevant to the question of sustainability. The model presented here participates fully to the investigation of these pressing questions, incorporates the relevant features of natural resources as well as the second law of thermodynamics and the question of dissipativity in a rather novel way.

By providing a non-linear and analytical foundation to the economic effects of resources depletion in a thermodynamic context, it is hoped that the approach can contribute at least partially to the designing of realistic quantitative scenarios of the evolution of anthropogenic civilizations. Specific non-linear economic aspects, such as stock-flow consistency, convexity, cyclical dynamics and the emergence of ergodic positions can all be concretely tested or predicted with the model when being sufficiently computationally endowed. It was also shown that reasonable parameter values already yield rather strong qualitative results, e.g. oscillatory behaviour. On the other hand, simple economic or energy/economic perturbations in a thermodynamic context result in problem diverging equiprobably if the state of the network is not carefully controlled.

Thus, system productivity has significant effects on the possible scenarios and offer substantial explanatory power with respect to medieval collapses or recurrent oscillations during the 19th or 20th centuries as discussed in.

ADVANCED RESEARCH

Science, Technology, and Innovation (STIG) are key elements for explaining economic growth. STIG systems descriptions build on concepts of evolutionary models of technological and institutional change as a coevolutionary complex adaptive system. Their relevant elements are interdependent and interact in nonlinear, positive feedback, and path-dependent ways. Interactions among STIG system elements are context-specific. Moreover, they operate typically under conditions of complexity, which means that their contributions to growth processes are not or only imperfectly observable and controllable. Also, knowledge is bifurcated into harder and softer parts within the different disciplines forming the relevant body of knowledge.

The two aims here are: (1) to reflect on the implications of Foundations of Complex Economic Dynamics for better understanding public policies; and (2) to motivate a multidisciplinary discussion of a broad range of key policy questions relevant for managing STIG systems. STIG systems are complex systems that coevolve economic, scientific, technological, and institutional dynamics, and are another level of complexity above the systems studied in Economics. They are examined with a view on the linking of policy research and practice debated in National Systems of Innovation and Economies of Knowledge. The two levels of complexity differ in several important respects: the nature and inclusion of relevant kinds of change; underlying conceptual formulations; and empirical investigatory, modeling, and policy analysis and design. Nevertheless, there are parallels worth exploring.

The relevance of a systems-theoretic approach for economic of STIG dynamics acknowledges that there is a multiplicity of different theoretical models relevant for STIG systems across disciplines. The complexity of the interaction processes of STIG systems gives rise to the reaction among different disciplinary theories as growth takes off or slows down. As a coevolutionary complex adaptive system behavior of STIG systems is nevertheless not arbitrarily, but boundedly random on the time scales of interest as they unfold either in a growth process or a limiting phase. A policy variant is that the nature and resulting efficiency of public interventions depend on the degree of complexity. Complexity beyond certain thresholds gives rise to an evolving meteoric literature debating some complexity measures, but a useful learning feedback based on those measures being fed into policy practice seems hard to come by.

The challenge is to understand whether and how software tools exist that are useful and helpful in different stages of the policy cycle. Examples are the systems-dynamics model of the economy developed in the early 1960s and further refined for that situation and purpose and the long-term projection models of multi-country macro-economic performances. In both cases, rapid growth and changing growth performance have been well captured and

understood in the base cases, but less so in some variant sub-themes as preserving public debt sustainability and keeping up with the continuing fast-paced change in available productive technologies up to even possible debt resolution. Existing tools being handicapped by the very sciences that helped develop them and usefulness for public policies has not kept pace with the increase in knowledge.

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