Introduction

Our goal, when we began this work some 15 years ago, was not modest. We hoped to initiate a fundamental reconsideration of the science of economics as it applies to dynamic relationships involving the production and exchange of goods and services, while remaining fully consistent with physical laws, notably the laws of thermodynamics. This work was originally inspired, in part, by the path-breaking work on non-equilibrium thermodynamics, led by Nobel laureate Ilya Prigogine (who died as we were making final corrections to this manuscript) and his colleagues, especially Gregoire Nicolis, at the Free University in Brussels. Prigogine and Nicolis' work introduced the fundamental concept of 'self-organization' creating 'dissipative structures' characterized by maximum entropy production and driven by a source of free energy far from equilibrium (Nicolis and Prigogine 1977; Prigogine et al. 1972). The first application of this theory was to explain some peculiar phenomena in chemistry. Subsequently a number of other applications have emerged, especially in biology.

We believe that some of these ideas are also applicable in economics. This has led us to reconsider economics also as a system far from (thermodynamic) equilibrium, in which the self-organizing forces are driven by a high level of dissipation of natural resources and solar energy. This view is, of course, very different from the standard neoclassical theory currently in vogue, wherein physical laws, materials and energy are essentially ignored. Our work is more consistent in some respects with the ideas of Nicolas Georgescu-Roegen, although we disagree with one of his principal (and pessimistic) conclusions (Georgescu-Roegen 1971).

Another important source of inspiration has been the pioneering work of Richard Nelson and Sidney Winter, who have led the application of ideas from biological evolution to economics (Nelson and Winter 1982). Finally, one of us (RUA) has been fascinated by the ideas of Jane Jacobs in the field of morals and ethics in human history (Jacobs 1992). Jacobs is not a card-carrying academic scholar, but her ideas seem relevant anyhow. Otherwise, thanks to recent progress in the behavioral interface, and the increasing use of game theory to understand transactions in real markets, we find that we have nothing substantively new to add to standard critiques of neoclassical economics except perhaps a more explicit attempt to consider the role of *H*.

Economicus in relation to another species we call *H. Custodius* and the relationship of both to *H. Sapiens*.

Our original goal may seem, at first glance, only slightly less ambitious than the physicist's search for a 'theory of everything' (which is, of course, no such thing). As Mirowski has noted, economics, being modeled on physics, but far more complicated, may once upon a time have aspired to such a grandiose vision (Mirowski 1989a). But this is no longer even remotely possible. Having modified our original ambitions, what we still do aspire to do is two-fold. First, as already said, we want to integrate dynamic economics and the relevant part of physics, namely non-equilibrium thermodynamics. (In later work we might attempt to introduce some ideas from contemporary physics, including quantum mechanics, but that would be another story.) Second, we aspire to provide some explanation of how the long-term behavior of societies and nations can be reconciled with the short-term behavior of individuals and firms. In short, we want to create a new dynamic microeconomics that is consistent with both physics and macroeconomics, especially the resource and environmental branches. At the same time, we recognize the need to address economists in their own special language, while also providing needed explanations in ordinary language as much as possible.

The limitations of the standard axiomatic paradigm of microeconomics are well known. They have been pointed out many times. Nevertheless, criticisms focused on unrealistic or false assumptions were generally – until the 1980s – brushed aside on the grounds, most famously articulated by Milton Friedman, that falsifiable assumptions are not important if the theory makes correct predictions. No critical test of predictability has yet been identified in the domain of microeconomics that both falsifies the existing model and points clearly towards an alternative behavioral model. The difficulty (we suspect) is that the conventional near-equilibrium theory did not make many predictions, even qualitative ones, unambiguously enough to be tested in such a way, at least until the 1980s when game theorists and behavioralists began to get into the journals.

Recent work by a number of social scientists and some economists has demonstrated clearly that the Walrasian neoclassical model of behavior cannot explain a number of pertinent facts. As the author of a recent textbook has noted:

> In experiments and real life, people frequently are willing to reduce their own material well-being not only to improve that of others but also to penalize others who have harmed them or violated an ethical norm. These so-called *social preferences* help explain why people often cooperate toward common ends even when defection would yield higher material rewards, why incentive schemes based on self-interest sometimes backfire, and why firms do not sell jobs. (Bowles 2004)

Bowles' book emphasizes the role of institutions, a perspective we find very illuminating though it is not our own.

However, we note (also not for the first time) that the existing model of microeconomics fails absolutely on the macro-scale. In particular, a utility-maximization theory applicable to individuals or simple owner-operated firms operating *myopically* in a static equilibrium does not and cannot explain innovation-driven technical change (a disequilibrium phenomenon) or economic growth as it actually occurs. For this reason, theories of growth, as expressed in models, have generally relied on growth-in-equilibrium propelled by exogenous drivers. The contributions of the so-called 'endogenous' theorists starting in the late 1980s have created some doubts and offered some new directions, but have not yet been successfully quantified. By contrast, our approach to micro-foundations is arguably more realistic and yet sufficiently simple and powerful to provide the basis or 'micro-foundations' for a dynamic *presbyopic* theory that can deal with disequilibrium, growth and change at both the micro-scale and the macro-scale.

Our new approach focuses on material wealth rather than abstract utility. It does not assume that preferences are immutable – they may be situation dependent. It does not assume perfect information. Bounded rationality is sufficient. Our approach demands consistency with the laws of thermodynamics, namely that the mass-balance principle must be satisfied in all transactions, while physical processes are also subject to the 'second law' (increasing entropy). In short, we depend less than standard textbooks do on convenient but unjustifiable assumptions, notably utility maximization, rationality and – most of all – perpetual equilibrium. We accept the notion that economic agents will maximize something like neoclassical utility to the extent that is possible subject to other constraints, while noting that much can be explained by the less demanding behavioral rule that economic agents will *not* consistently make decisions that will reduce their material wealth. (In this sense, our theory is closely related to so-called 'rational expectations'.)

Our contributions to fundamental theory, we think, are as follows: (1) to modify and broaden the conventional utility theory, making it applicable to non-equilibrium and dynamic situations, and consistent with decision theory (2) to introduce the laws of thermodynamics explicitly into production and consumption processes without invoking an awkward and hard-to-explain symmetry between them and (3) to offer a new tool for simulation analysis, as an alternative to the standard constrained maximization approach. Finally, we hope to treat technology and technological change in a more realistic way, although that discussion is mostly reserved for a subsequent book.

For a time, having been inspired by the work of Nelson and Winter previously cited, we seriously thought of our work as a contribution to the sub-specialty known as evolutionary economics. Our theory is evolutionary in the sense that it reflects irreversibilities (of several kinds) and is consistent with a quasi-Darwinian rule of survival of the 'fittest', leaving the exact definition of fitness to contextual determination. However, we now think that evolutionary economics, as expounded by its chief proponents, depends too much on a questionable analogy with evolutionary biology. In biology, it is accepted that mutation is a random process driven by environmental influences, such as contact with mutagenic chemicals, climate change or ultra-violet radiation. Mutation generates diversity in the genome, while Darwinian selection operates to weed out the harmful mutations and propagate the beneficial ones. The observed pattern of alternation between periods of slow and rapid speciation (known in the trade as 'punctuated equilibrium') can, perhaps, be explained in terms of the slow buildup of beneficial mutations reaching a critical threshold.

However, we hold that discoveries and inventions do not occur in random fashion – unlike mutations. Moreover, radical general purpose innovations, which are the triggers of economic change, may – in some cases – be facilitated by an accumulation of small incremental improvements in other areas, but a necessary condition for radical change may not be sufficient. Great leaps forward are rare but of overwhelming importance to the economy. Yet they are not explained by ordinary economic behavior. In short, technological progress is not closely analogous to biological evolution, as we point out in a later chapter.

A final motivation for this book is that neoclassical theories and oversimplified models with unrealistic assumptions about technology are being used to provide policy advice at the highest levels of government, some of which is dangerously short-sighted and – we think – fundamentally perverse. Although this book is not policy oriented, we are uncomfortable with any theory that assumes existing trends are optimal – that this is, in effect, 'the best of all possible worlds'. We want to call attention to this fundamental problem and offer some suggestions as to viable alternative models.

Chapter 1 reviews and discusses the behavioral issues. *Chapter 2* reviews and summarizes the inadequacies of the standard neoclassical paradigm, even though they are well known. *Chapter 3* introduces our proposed alternative set of micro-foundations, namely the decision rules governing the actions of individuals and firms. *Chapter 4* develops the properties of the Z-function, which is the main analytical building block of the new theory. *Chapter 5* continues with a detailed discussion of short-term economic decision-making and markets where the role of technology (knowledge) can be neglected. *Chapter 6* extends the static theory into the time dimension, making it dynamic and enabling us to create a more realistic theory of production and trade. The importance of the Z-function here may be that it need only be differentiable to permit a dynamic theory. Integrability conditions, as in the neoclassical theory, are not required. In this chapter we also begin the discussion of the role of learning and knowledge as drivers of progress in the long term. *Chapter 7* discusses the transition from micro to macro, and the problems of aggregation. *Chapter 8* focuses on phenomena that occur only at the macro-level and that require a different and larger framework. Money plays a central role in linking the micro-world to the macro-world. At the micro-level, the quantity of money in the system is implicitly assumed to be constant, but its societal role is invisible. In the macro-world, money is an endogenous variable of the system. Similarly, technology is exogenously given at the micro-level, but is at least partly endogenous at the macro-level. But invention, diffusion and innovation are macro-phenomena that are also strongly influenced by external circumstances and events. We also consider, albeit very briefly, the problem of aggregate social wealth, and the relationship between the standard measure (GDP) and other factors.

In *Appendix A* we consider the multiple roles of money as a medium of exchange, a surrogate for wealth, and as a social artifact. *Appendices B, C,* and *D* further develop the mathematical tools and display simulation results.