MODELING THE ECONOMY AS A DISSIPATIVE STRUCTURE

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Overview

We provide a formal framework allowing to embed macroeconomic modeling within the thermodynamic realm.

While distribution and aggregate demand legitimately primarily depend upon the social interaction of economic actors, the production capacity is the most obvious contact point of economics with the physical realm in which it is embedded, and must be constrained by the laws of thermodynamics. The human economy is viewed as an open complex system, perpetually trading energy and matter flows with its environment to sustain, grow and complexify itself. By application of Prigogine's description, an economy is therefore considered as a dissipative structure, that is, a thermodynamic system far from equilibrium.

Methods

Material goods are envisaged as low-entropy matter, whose economic usefulness rests on their internal order. Their production is modeled as a thermodynamic conversion, operated on a finite stock of resources. The physical consistency of the process obtains courtesy of a minimal disaggregation of productive firms into at least two sectors of complementary thermodynamic roles: The energy sector, producing a flow of useful energy based on the depletion of high-potential energy resources, and a matter sector which uses the flow of useful energy as intermediary consumption so as to create order into initially economically-useless unshaped material resources. Part of the flow of material goods generated is reinvested into the growth of the economic metabolism. The rest is exuded as consumption wastes.

Our formalism combines the axiomatic formulation of irreversible finite-time thermodynamics with the postulate that macroeconomics relies on social interactions between agents identified by their emergent aggregate behaviors and stock-flow consistent accounting relations. The stylized skeleton of the social structure of the economy is drawn in such a way that its dynamics boils down to standard economic models when resources abound. The monetary structure of the economy is shown to mirror the first law of thermodynamics —the conservation of matter and energy—, and enables to assess the consequences of the second law —the inevitable long-term decay of all closed systems towards equilibrium.

Results

This first successful modeling of the economy as a dissipative structure sheds new light on the thermodynamic view of the economic process and predicts early warning signs of the depletion and degradation of nonrenewable resources. Order creation within the economic system as well as the greater, counter-balancing entropic pressure it exerts on its environment can be quantified, and the flow of useful work fueling the local creation of order is highlighted as a prime indicator of the metabolic activity of the economy, assessing simultaneously the quantity and the quality of its production.

We highlight the effects of resource scarcity on GDP and other economic indicators like under-employment, relative prices and inequalities. In particular, when matter resources become scarce but energy resources still comparatively abound, the unavoidable long-term collapse of a finite stock economy is shown to be preceded by a primary slowdown of the real growth rate of the economy accompanied with the flattening of its endogenous business cycles and rising inequalities —all of which have been observed in recent years. By comparison, when energy becomes scarce before matter does, except for rising inequalities, the collapse is unannounced and more abrupt: it evokes a

Seneca cliff. The asymmetry of these ‘’weak signals’’ would not be deductible from a simple stylized resource model that does not specify the distinctive, non-exchangeable roles of both types of resources.

Finally, the model allows to conclude that a mere increase in capital efficiency cannot solve the situation, but only an urgent socio-technological shift towards a flow economy relying both on matter recycling and renewable energies.

Conclusions

These theoretical advances open up the path for a whole new family of ecological macroeconomic models. Their task can now be understood as modeling the ecological shift as a transition from a stock economy to a flow economy —the unique way to remain sustainable in the long run.

The rapidly growing literature on material flow analysis provides today significant data on the through-flows of energy and matter resources that sustain economic systems far from equilibrium. Combined with the analytical setting proposed here, this wealth of data should allow to address the sustainability in terms of matter and energy depletion of development scenarios and economic prosperity at large.