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Short communication

Systems diagrams for visualizing macroeconomics

Thomas Abel

NSF International Post Doc, National Taipei University, Taipei, Taiwan, ROC

For an anthropologist like myself the work of H.T. Odum has great significance. For 40 years his research has explored the workings of open systems of all sorts found in nature, including the biosphere's systems of humanity (Odum, 1971, 1983, 1996; Odum and Odum, 1976, 2001; Odum et al., 1998). There is perhaps no more interesting systemic relationship than that between people and nature, and between people and other people. For anthropologists therefore, the research of H.T. Odum can provide essential understanding of the functioning and dynamics of the ecosystems that have co-evolved with humans as foragers, as agriculturalists, as archaic states, and as they exist within contemporary world systems. Systems principles of hierarchy, scale, diversity, self-organization, and others can each be applied to understand cultural self-organization.

A direct outgrowth of H.T. Odum's work on human-environmental systems has been his interest in ecological economics (Odum, 1996). Many of the other articles in this issue have addressed emergy, and I will not re-review the concept or methods. This paper will instead assume a familiarity with emergy accounting and systems ecology, and add to them an anthropologist's understandings of sociocultural self-organization, political-economy, and cultural evolution as they can enlighten and enliven the debate between ecological economics and neoclassical economics.

This article will present a visual "discussion" of the underlying "basic assumptions" of macroeconomics as they can be compared to the fundamental principles of emergy accounting and systems ecology. I will begin with a well-known diagram and some discussion of the contrasting worldviews embodied in the two forms of economics. The macroeconomic worldview, as exhibited in Fig. 1, does not explicitly incorporate topics like political power, military force, demographic stress, or social inequality. These issues for many anthropologists, however, are essential to understanding the evolution of culture, and as well as contemporary world political-economies (Wallerstein, 1974; Carneiro, 1982; Johnson and Earle, 1987; Adams, 1988; Tainter, 1988; Harris, 1989; Sanderson, 1990; Chase-Dunn and Hall, 1997). Neither does the macroeconomic model explicitly incorporate an ecologist's concerns with finite natural resources, replacement times, or other limits on production in natural, open, environmental systems. I argue that these considerations are essential in any model that addresses the complex nature of human–ecosystem and human–human relationships. I will use this discussion to point to serious omissions in the macroeconomic model (see also Hall et al., 2001). Finally, I will demonstrate that an energy systems model can easily incorporate these vital concerns of anthropologists and ecologists.

1. Macroeconomics and environmental accounting

1.1. Step 1: the circular flow of income

A common diagram in macroeconomic textbooks is the "Circular Flow of Income" (Fig. 1). It depicts the relationship between "business firms" and

E-mail address: tabel@mail.ntpu.edu.tw (T. Abel).

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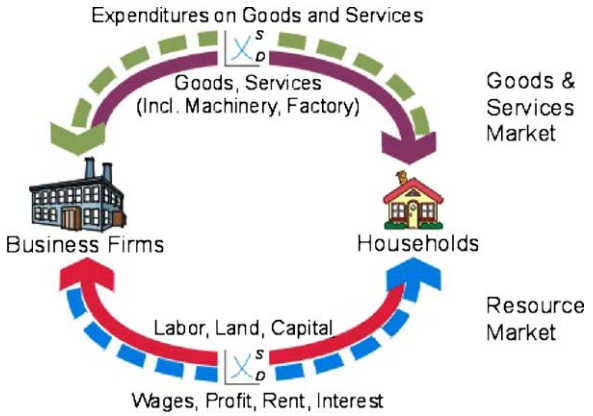

Fig. 1. The circular flow of income. This basic model can be found in every macroeconomics textbook. The assumptions of the model should be examined from the systems perspective. Dotted lines represent money flows.

"households" in a market economy. I will step through it. In its simplest form, households provide labor, for which they receive wages from business firms. This is depicted in the lower flow of Fig. 1. Business firms supply "goods and services," for which they receive payment from households. This is depicted in the top flow of Fig. 1.

In addition to labor, however, "households" are also said to provide land, capital, natural resources, and other assets, which are exchanged in a "resource market" for profit, rents, interest, etc. (lower flow of Fig. 1).

Furthermore, in addition to household goods and services, "households" are also said to purchase various fixed goods (machinery, factories, equipment, raw material stocks, etc.) in the "goods and services market" (upper flow of Fig. 1).

While it might be a useful logical category for economists, the term "households" is therefore an odd assortment of both persons and assets. The assets of a "household" may include the physical assets of a firm. They also include storages of natural resources, which in this model are owned or controlled by the "household."

This leads to two shortcomings of the economists' diagram. First, the term "business firms" has no physical reality, but is rather an abstract nexus of interactions between "households." Second, the term "households" is in fact both households and industries and the owners of each.

1.2. Step 2: a hierarchy of "households"

Fig. 2 expands the "households" of the first diagram into the physical hierarchy of households and corporations (and their owners). This diagram splits the (lower) flow of land, labor and capital. Here simple households supply labor, and the "owners" of businesses supply their labor, their land, capital and other assets to the "resource market." In exchange, simple households receive wages, while the owners receive profits, interest, and rents.

This diagram also splits the (upper) flow of goods and services. Here simple houses receive household goods and services, while the owners of business firms also receive fixed goods such as machines, equipment,

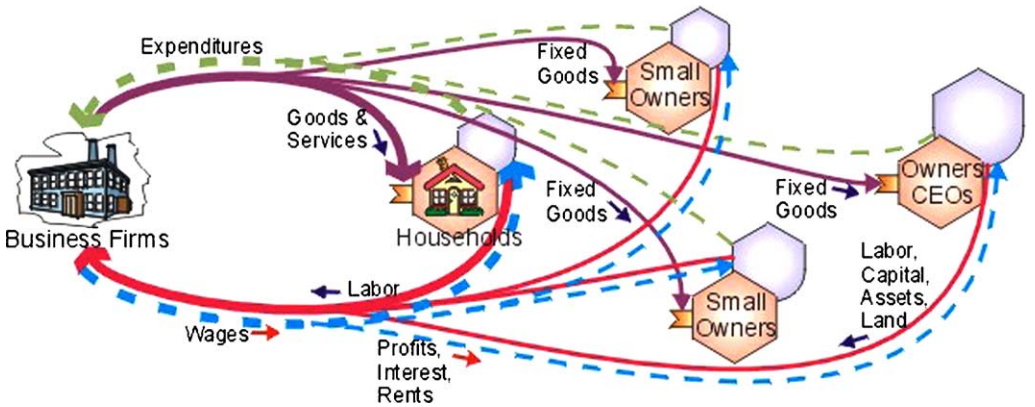

Fig. 2. A hierarchy of "households." A society is composed of family groups and their assets in households. Households can be placed into a web or hierarchy of production.

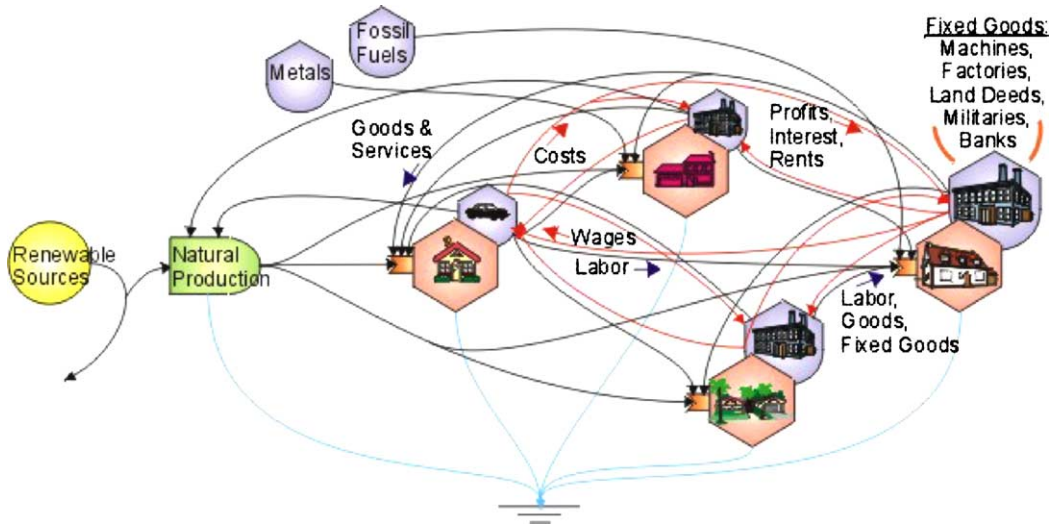

Fig. 3. Flows of emergy and income. Humans are parts within ecosystem wholes. They should be modeled within those systems in order to identify the natural resources that drive the system.

buildings, etc. which they purchase in the "goods and services market."

1.3. Step 3: flows of emergy and income

Fig. 3 completes the transformation of Fig. 1 into a systems diagram in the format of Odum's famous symbols and structural logic. The abstract "business firms" figure is eliminated, since the physical presence of a firm is logically located physically with its owner. A firm does not exist without ownership and management. Rhetoric about "corporations" or the "business sector" are common abstractions that obscure the unequal social relations of capitalist production. Owner and firm are co-occurring components of an economy and neither can exist without the other. The logic of ownership is that owners gain security, power and prestige from the control of productive assets, which they feedback to amplify production (when possible) and defend their positions in socioeconomic hierarchies. This fundamental principle of economic intensification is known from chiefdoms, archaic states, and contemporary states, and has been a critical component of their evolution (Fried, 1978; Harris, 1979; Johnson and Earle, 1987; Abel, 2000, pp. 354–454).

Fig. 3 finishes the story by filling a gaping hole in the macroeconomic model. As has been shown on many occasions (Gorgesccu-Roegen, 1971; Daly, 1973; Cleveland et al., 1984; Hall et al., 1986; Martinez-Alier and Schlupmann, 1987), the neoclassical macroeconomic model ignores the material contributions of natural resources, most egregiously energy sources like coal, oil, or geothermal energy. Natural assets and their location in the hierarchies of ecosystems and the biosphere are now added to the diagram. It adds renewable sources (sun, wind, rain), natural production (crops, timber, etc.), and non-renewable sources (metals, fossil fuels, etc.) that drive any ecosystem or economy. The absence of these sources from the macroeconomic diagram belies the minor role they play in the economist's model, though in fact they are critical (Hall et al., 2001).

Political-economic inequality (the social hierarchy) is now present in the model (see Abel, 2003 for further discussion). People are located in a social hierarchy by differential control of physical assets. Starting from the left in Fig. 3, labor households reproduce themselves, control small asset storages, and produce the labor required by firms on the right. Moving right in the diagram is a hierarchy of owners and their firms. In each of these owner symbols, labor is combined with assets to produce new goods. As shown, the assets may be renewable natural products, non-renewable storages, or secondary goods from the economy. High-emergy goods are concentrated

into storages on the right, which will have powerful feedback effects over large territories.

Some critical storages of assets in state systems are machines, factories, legal deeds, militaries, and banks (Fig. 3). Legal deeds to land and property are important assets preserved in government storehouses. The punitive force of the courts and state military apparatus back these guarantees and defend social inequality. Banks provide loans, which are another critical component of the economic system. Money is concentrated into banks, from which loans are granted at interest.

Now in systems diagram form, Fig. 3 re-conceptualizes the macroeconomist's model of the human economy as a model of the human ecological-economy. Here political-economic hierarchy is coupled to a model of environmental self-organization and natural resource provisioning and limits. Both the ecologist's and anthropologist's objections are met.

1.4. Step 4: gross domestic product, GDP

One last diagram takes the discussion into the backyard of the neoclassical economist by re-representing one of its fundamental principles—GDP. To succeed, the diagram details the functional relationships that exist between industry, political officials, and financial elites in contemporary capitalist states. It is here argued that these elites utilize their asset storages to amplify production to themselves, and by doing so, amplify production to other elites and to the system as a whole.

Money moves in countercurrent to goods and services within an economic system (Odum and Odum, 1976). In environmental accounting however, the driving forces of the system are not the money, but are instead the high emergy sources and storages that flow into the system. These are depicted in Fig. 4 as re-

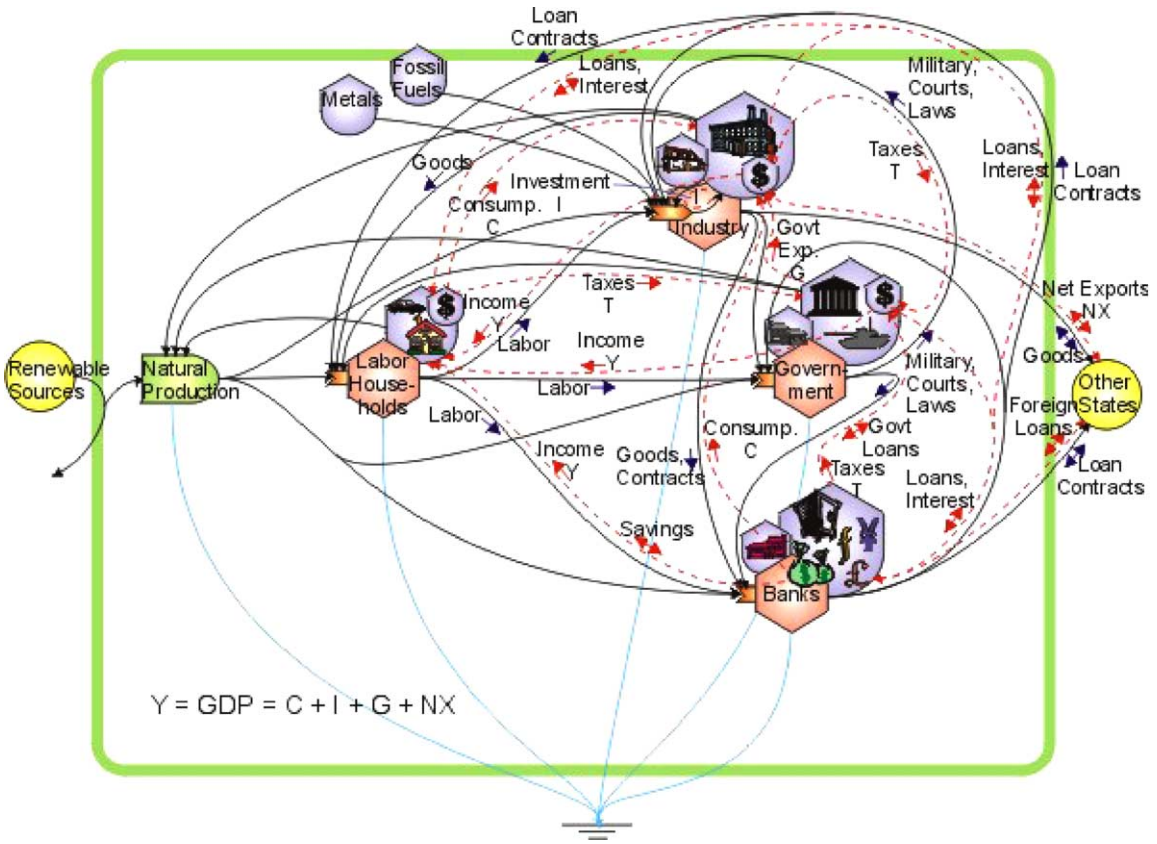

Fig. 4. GDP and emergy in a nation.

newable sources, trade from other states, and the storages of metals and fossil fuels. These flows constitute a knowable and finite flow of emergy into a system each year. GDP measures the money that circulates in countercurrent to these flows.

In Fig. 4 you see the same hierarchy of households and owners from Fig. 3. In Fig. 4 the owners have been subdivided into industry, government, and financial elites and the assets they control. It is now possible to represent the flows of currency in the GDP model. Gross domestic product (GDP) is said to equal the sum of consumption (C), investment (I), government expenditures (G), and net exports (NX). This diagram differs from an economist's model by depicting the functional relationships between government, industry and financial institutions, as they reinforce the production of each other. For example, the role of banks as the suppliers of international currency is shown. Banks depend on secure and durable storage technologies from industry, and on the legal, judicial, and punitive institutions of government to assure the security of their currency storages.

The ecological-economic buying power of the money in an economy can be calculated by dividing the emergy use by the money expended for final purchases in an economy (the GDP) (Odum, 1996). This index, called the emergy/money ratio, may be used to compare national economies, and to calculate appropriate exchange rates.

2. New assumptions for an ecological-economic model

Given this discussion, two important principles can be stated:

(1) "Labor" is mislabeled as a "resource" in the resource market. Labor is a *product* of ecosystems, not a resource as in a source of energy or raw materials that fuel production chains. People are themselves top consumers in ecosystem hierarchies, the natural systems upon which economies are constructed. In a web of ecosystem life there are feedbacks from people or animal consumers which can amplify the capture of available natural resources, and amplify the useful work performed with those resources. But it is natural resources upon which all life depends.

(2) Natural resources are not a market commodity like any other. They are the energetic sources that drive an ecosystem with humans. Natural resources like sun, wind, and rain are potential and kinetic energy sources. Carbon sources like crops, wood, hydrocarbon fuels (coal, gas, oil), and animals are storages of chemical bonds that can be broken to release energy and do work. Solar energy and the geologic energy of present and past millennia place finite limits on the quantities of stored natural resources. An economic model that depicts nature as a substitutable market good ignores these facts of thermodynamics and physical chemistry. It unrealistically assumes that there is always a substitutable market good to replace any depleted source. This is an unfortunate and dangerous "basic assumption" of neoclassical economic theory.

3. Conclusions

H.T. Odum has given the world a synthetic theoretical framework for understanding natural systems. General principles of hierarchy, scale, and self-organization can be applied to political-economic hierarchy, inequality, power, and production. General principles of natural, open, thermodynamic systems of the biosphere can be applied to positioning human economics within the flows of provisioning resources that constitute them.

Odum's holistic theoretical framework and methodological toolkit make it easy to discover and expose the biases of the neoclassical macroeconomic model. This paper uses systems modeling to communicate some critical shortcomings that are hopefully more transparent than ever. The political-ideology of unlimited growth divides the economic from the ecological-economic worldview. Ecological-economic models recognize energetic limits in the biogeophysical world. Odum's legacy is a roadmap to clarity in this too often obscured and confounded study of greatest importance to us all.

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