INVESTIGATING DECOUPLING AND STRUCTURAL DYNAMICS VIA THE "HARMONEY" BIOPHYSICAL ECONOMIC GROWTH MODEL

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Overview

Scientists and economists often seek to understand the linkages among natural resources consumption, the cost of resources, and both the size and structure of the economy. The size of an economy can be measured by many metrics such as gross domestic product (or net output), gross output, population, the quantity of physical capital, and others. The structure of an economy can be measured by distributions and summary metrics that summarize the distribution of stocks (e.g., capital) and flows (e.g., income, energy) among people, companies, economic sectors, or other categories through which money and natural resources flow.

All models are simplified representations of real-world processes, and thus highly stylized models are useful for providing insight into real-world data. Thus, there is value in understanding whether even non-calibrated models can at least conceptually mimic trends in economic data. Here we demonstrate the ability of the Human and Resources with MONEY (HARMONEY) model to mimic high level energy and economic relationships observed in global and U.S. economy data. We explore the concept of resource (or energy) "decoupling" by comparing model simulations to global data. We define relative decoupling as a situation with a lower energy or resource consumption growth rate than the GDP growth rate. We define absolute decoupling as a situation with negative energy or resource consumption growth rate and positive GDP growth rate.

Methods

This paper compares the structural and size metrics of the U.S. economy from King (2016) to simulated results from the HARMONEY model of King (2020). HARMONEY is a combination of the Goodwin-Keen (Keen, 2013) economic growth model and the Human and Nature Dynamics (HANDY) biophysical model of Motesharrei *et al.* (2014) in the form of a 2-sector (industrial) economy that extracts a regenerative natural resource (i.e., a forest). The model is stock and flow consistent in its approach to tracking both monetary and natural resources stocks and flows. The two sectors are a "goods" sector that outputs new capital (machines), and the "extraction" sector that extracts resources. The extracted resource flows are used to (i) operate capital in each sector, (ii) become embodied into new capital (investment), and (iii) feed the population. Output from each sector is a Leontief production function where capacity utilization adjusts as required to maintain conservation of flow of natural resources. Population birth rates are constant, but death rates decline as a function of per capita household resources consumption. Firms choose how much to invest in new capital as a function of profit share. Firms acquire debt (credit) from private banks if investment is greater than profits. Banks do not discriminate loans to firms (e.g., there are no credit restrictions).

Price for each sector is solved as a constant markup, μ, on costs, c, where the full cost of production per sector includes its (i) intermediate demands from each sector, (ii) wages, (iii) interest payments on debt, and (iv) depreciation. We compare simulations with the full cost assumption to those with a "marginal cost" assumption that neglects interest payments and depreciation.

Results

We very briefly summarize two results. The first, Figure 1 describes the relationship between the growth rates of energy (or resource) consumption and Gross World Product (GWP). The second, Figure 2, describes an information theory metric indicating the internal distribution of transactions in the U.S. and HAMRONEY input-output tables. In Figure 1, both the data and the model show a clockwise temporal pattern. When growth rates were increasing, the ratio of energy:GDP growth rates is near or slightly above a 1:1 ratio (i.e., constant to increasing energy intensity). When growth rates are decreasing, the growth rate ratio declines below 1:1, with the global data residing at a 2:3 ratio since the 1970s (i.e. decreasing energy intensity). Importantly for understanding energy decoupling, in HARMONEY this clockwise pattern occurs independently of assuming increases in any efficiency parameters. That is to say, the transition to a growth regime with declining energy intensity is *not* necessarily indicative of choices to increase the energy efficiency of machines. It is indicative of the inability to grow at increasing growth rates (or continue growing at an accelerating growth rate). Nonetheless, if one assumes increases in resource consumption efficiency starting at the beginning of the simulation, the HARMONEY model does further "decouple" as witnessed by the changes from the black to gray solid lines (full cost assumption) and black to gray dashed lines (marginal cost assumption). However, changing the assumption for calculating the cost of production produces an even larger appearance of relative decoupling. This is shown by the changes from the solid (full cost) to dashed (marginal cost) lines: black when considering no efficiency and gray when considering increasing resource consumption efficiency of capital.

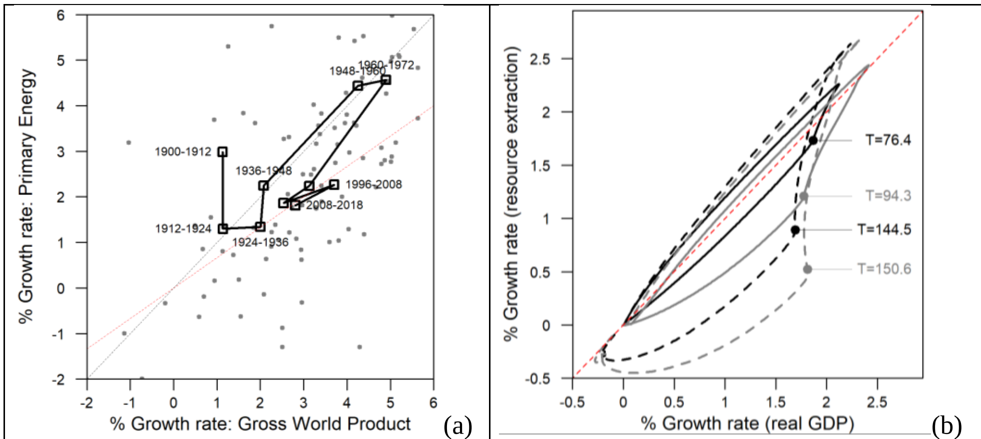

Figure 1. (a) Global data (1900-2018) indicating annual growth rates of primary energy consumption versus annual growth rates of gross world product. Squares average growth rates every 12-years. (b) The parallel figure of (a) for four HARMONEY scenarios showing the growth rates of natural resource extraction versus growth rates of real GDP. The indicated time periods show the time in the simulation when profits peak and decline toward zero due to reaching peak resource extraction rate. **Black solid:** full cost, no efficiency increase. **Black dashed:** marginal cost, no efficiency increase. **Gray solid:** full cost, efficiency increase. **Gray dashed:** marginal cost, efficiency increase.

Figure 2 shows the "internal structure" of the economy during its growth phases. Calculations from King (2016) for the U.S. benchmark input-output (I-O) Use tables are shown in red with key years labelled. Figure 2 shows the same HARMONEY simulations as in Figure 1. Keys for interpreting Figure 2 are (i) information entropy = mutual constraint + conditional entropy, (ii) conditional entropy increases as all transactions of the I-O table become equal to each other (i.e., a uniform I-O matrix), and (iii) mutual constraint increases as each sector transacts equally with *only one* other sector (e.g., a diagonal matrix). Consider two key takeaways from Figure 2. First, both the U.S. data and HARMONEY model show a counter-clockwise trend (Figure 2(a)), indicating that HARMONEY incorporates realistic physical and cost feedbacks indicative of a real economy. Second, the rising information entropy (Figure 2(b)) is indicative of self-organizing systems with the potential to grow relative to their environment, while the decrease indicates diminishing ability to grow relative to resource extraction capability.

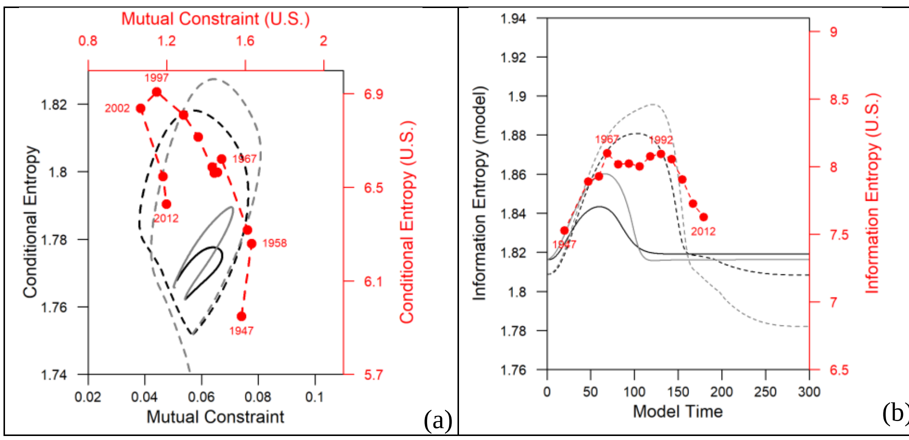

Figure 2. A comparison of metrics of the "internal structure" of economies via the I-O tables. (a) Conditional entropy versus mutual constraint. (b) Information entropy = mutual constraint + conditional entropy. U.S. economy calculations from King (2016) and HARMONEY simulations are same as in Figure 1.

Conclusions

The HARMONEY model effectively mimics (or reproduces) the broad structural trends and relationships between macroeconomic indicators that characterize the high-growth (high-carbon or fossil-based) phases of the global and U.S. economies. In this way, HARMONEY provides a physically and economic consistent framework to effectively describe the growth and structural changes that will be associated with a low-carbon energy transition.

References

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