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Earth System Dynamics
Discussions

Interactive comment on "Long-run evolution of the global economy: 2. Hindcasts of innovation and growth" *by* T. J. Garrett

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This is the second time that I have the opportunity to comment on Tim Garrett's work in this journal. Garrett explores in a systematic way his own approach to analysing the long-term evolution of the Earth system in conjunction with the human economy. In my earlier contribution (see Garrett's responses on my arguments, Earth Syst. Dynam. Discuss., 2, C164–C174, 2011 www.earth-syst-dynam-discuss.net/2/C164/2011/) I have already commented on several aspects of his models that I deem problematic. I will not pick up these points again here. Further, the new paper builds on a modified version of the model that has been published in 'Earth's Future' (http://onlinelibrary.wiley.com/doi/10.1002/2013EF000171/abstract) and which I regard to be a major improvement. So, the reader has to refer to this work in order

to understand some details of the model used in the current paper. This is particularly important in the transition of the narrative in section 2.4, where new concepts are introduced that do not play an explicit role in the previous sections, in particular, the 'decay parameter' and 'diminishing returns'. The basic idea of this work is to consider the global economy as part and parcel of a physical system which realizes energetic transformations, and to reach a level of abstraction that allows to focus on the physical constraints and mechanisms that would enable systematic predictions about future developments. This approach has the great advantage that it does not need to disaggregate the economic system, which is normally done by IAM models. These models have to introduce certain assumptions about economic variables which are highly problematic, therefore rendering predictions almost arbitrary, as has been stated clearly in a recent assessment by a leading economist working in this field (see Pyndick 2013). Therefore, Garrett's approach is highly welcome. Methodologically, it relates with Maximum Entropy methods in Earth System analysis which also aim at reducing complexity in focusing on the constraints under which the system operates (e.g. Kleidon 2011). However, these approaches so far lack an explicit modelling of the economy (for a seminal contribution, see Haff 2014). So, Garrett's efforts clearly deserve attention. There are strong and convincing arguments that continue to be overlooked in much research on the relationship between the economy, energy and Earth System dynamics, such as the simple fact that the relevant economic system can only be the global economy ('civilization' in Garrett's terms) (for example, as Garrett also discusses, assessing rebound effects is only meaningful on this level). In his view, economic systems build the capacity of harnessing energy to generate work which feeds back on this capacity, thus creating the potential for growth. He proposes a simple measure for this capacity, which is the integral over the series of past annual global production, i.e. inflation-adjusted Gross World Product, which he calls 'wealth'. For his predictions, the empirical regularity is essential that there is a fixed ratio between energy consumption and this measure. This regularity has been shown to exist in his previous work and should not be confused with a fixed energy throughput per unit of annual GDP, which is

normally considered. Once this empirical regularity is accepted as a fact it is straightforward, as Garrett shows, to define a 'rate of return' of economic activity in terms of additional energy throughputs gained through time, and to interpret the changes of this rate as 'innovation'. That means, since wealth is an integral over time, current growth is determined by past innovation and current innovation. His statistically based narrative of recent economic growth is convincing to me and matches with related views in the literature (such as Murphy and Hall 2010 on the EROI measure). In my earlier review, I already questioned the definition of wealth. It comes close to the economic notion of 'capital', but uses gross values of production that do not include depreciation. However, depreciation is introduced in section 2.4 as a 'decay parameter'. I think that this should be considered also in the definition of wealth, in order to be exact in the economics. In other words, I think that Garrett now includes physical decay, but not economic depreciation (in other contributions, this is related to inflation, which I think is bad economics). So, I have the impression that the two parts are not consistent, because including decay was one of the improvements that I noticed in the new model. As for the measure of wealth, that would imply using NWP Net World Product in the original time series. Further, Garrett states that the physical manifestation of wealth is networks, both technological and human. This perspective is essential for arguing that in measuring global production, it is not necessary to distinguish between investment and consumption, as we can conceive of consumption as producing and maintaining the human network. Obviously, this presupposes a fully-fledged materialist theory of human consumption activity (such as in the arts, fashion etc.) in relating all this to the energetics of the economy. I think that this is possible (see my own work, Herrmann-Pillath 2013). However, this also means that using the GWP as a measure may be problematic because the GDP data do not include the production of public goods by political entities funded by taxes. This is a well-known limitation of national accounts and certainly is highly relevant for Garrett's argument. For example, roads, airports, harbours or power stations as essential parts of the 'hardware' of the economy would be left out of Garrett's measure of wealth (and he explicitly mentions these parts). This

also pertinent for the analysis of innovation, which in New Growth Theories is treated as a positive externality (so, by definition is excluded from national accounts). Another technical problem is the use of market exchange rates for measuring GWP which Garrett simply imports with the data base that he uses. I think that only purchasing power parities make sense, given the focus on energetics. As is well known, market exchange rates distort the measurement of the true standard of living. Especially for less-developed countries. However, it is this 'real' level of economic activity that drives energy transformations. So, I think PPP conversions should be used. Considering my arguments an on necessary modifications of the fundamental quantities, the questions arises whether the empirical regularity of a fixed ratio between wealth and energy use would survive the statistical corrections. I have no preconceived opinion on this, but of course the challenge is that we cannot implement those corrections, especially we cannot measure the stock of public goods over longer time periods. Therefore I advise that Garrett should present some reasons why he regards his measure as a good approximation. Garrett's work concurs with views such as articulated in Ayres and Warr (2009) that innovation is tantamount to improvements in energetic conversions, in his words, the rate of return. I agree with this view, but want to point out that this also means that an essential driver of economic growth remains unexplained, just as in the earlier neoclassical growth models that Garrett briefly sketches in the appendix. So, the question is whether this is also a weakness for a physical model advocated by Garrett. In his narrative, technological progress happens because of both technology and availability of reserves. Thus, one would guess that a standard economic model of resource extraction with technological change would be a proper complement. However, as has been shown by authors such as Kümmel (2013), this approach would probably commit the mistake to assume that technology is a full substitute for energy. So, at this point a step towards further disaggregation of the physical model seems unavoidable. To sum up, Garrett's work is highly productive in opening up new ways of thinking about the human economy in the Earth System context. He tries to see the forest, whereas much modelling practice is busy with counting the trees.

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