Earth Syst. Dynam. Discuss., 6, C339–C345, 2015
www.earth-syst-dynam-discuss.net/6/C339/2015/

Earth System Dynamics Discussions
Open Access

Interactive comment on "Resource acquisition, distribution and end-use efficiencies and the growth of industrial society" *by* A. Jarvis et al.

A. Jarvis et al.

a.jarvis@lancs.ac.uk

Received and published: 5 June 2015

Response to Anonymous Referee #3 Received and published: 15 May 2015

"This paper presents an interesting although perhaps provocative view. The authors interpret global economic growth through the perspective of physical network theory. I have some major difficulties with the paper. The authors adopt the conceptual model of a space-filling network that expands over time. They use analogies from biology describing the structure of organisms. However, they don't provide any real argument that this has any relevance to the global economy."

With respect, we believe we do show that the global economy exhibits behaviours that are somewhat analogous to those observed in nature. It is unequivocal that networks

Full Screen / Esc
Printer-friendly Version
Interactive Discussion
Discussion Paper

connect resources and points of end use in society and that mass moves through these networks. The question we are exploring is what form these networks take and what implications this has for the growth of society. These networks are most definitely directed. We present evidence to support the theory that they are also near optimal in terms of their distribution efficiency. With regards to their “relevance to the global economy”, we think it is beyond argument that the components of the global resource distribution network (i.e. roads, railways, airline routes, shipping routes, cables, pipelines, etc.) are critically important to the global economy and that understanding how mass moves through them will reveal something about how industrial society operates.

"Resources are extracted at the point where they exist (influenced by economic and practical constraints which have changed over time) and usage is wherever the largest energy demands happen to be (which in large part depends on historical contingencies and energy availability, and therefore may bear little relationship to modern energy production)."

We don’t disagree with any of this and it in no way refutes a network view of the expansion of industrial society. However, it is simply wrong to assume we simply describe “modern energy production” as is inferred here. The paper explicitly ties the contemporary energy landscape to the evolution of the global energy system over the last 160 years.

"The spaces in between are not necessarily filled, and the economic organisation has not grown larger in any way analogous to a biological organism."

With respect, R3 does not know that. The global economy must be counted as one of the most complex objects in the known universe which is why there is so much debate and uncertainty over its operation.

"There is little economic activity in the vast bulk of the oceans, polar and mountainous regions."

ESDD

6, C339–C345, 2015

At no point do we assume or state that space is filled uniformly. Indeed, we state:

If the global RADE network has the dimensions of D = 3, then the scaling observed between x and x* suggests that, at the global scale, the distribution networks that underpin the RADE system are, in aggregate, optimised with respect to energy losses, despite filling a highly irregular three dimensional space. (p143)

Building on the biological metaphor; a tree fills space, but there is lots of spaces between the leaves and the roots where the tree isn't present and where photosynthesis and other metabolic processes involving the translocation of mass (carbon, water, other metabolites) does not occur.

"Moreover, transport distances are surely bounded by half the circumference of the planet, with an average of half that value."

This is a simplistic view of the topography of the space in which industrial society operates. What about exploration in the vertical (mines, wells, tall buildings), or space travel, or that paths may need to deviate from the shortest physical distance due to other factors (mountain ranges, ice caps, political or civil unrest. . ..)? More importantly, although the space occupied by the planet is fixed, the potential pathways that can be exploited within this space are infinite. So the opportunity to grow into finer and finer divided space is not bounded simply by the circumference of the planet.

"Australia exports large quantities of coal, OPEC exports oil (and has been doing so for many decades). Where is the network expanding physically, recently and in the future?"

With respect to the expansion of the network close to points of resource acquisition, the portfolio of energy being extracted globally has always been in a state of flux. New resources are constantly being accessed in increasingly disparate locations to meet growing demand and replace reserves that have been exhausted. To list a few recent examples: oil from tar sands in Canada; fracking for gas and oil in the USA; the

ESDD
6, C339–C345, 2015

production of gas in Qatar for export as LNG; Norwegian oil and gas; the expansion of wind, solar and other renewable energy production the world over. In each of these instances the network has clearly had to expand physically in order to facilitate resource acquisition.

Even with respect to the specific “mature” points of acquisition mentioned by R3 (ie OPEC oil and Australian coal) the continued exploitation of these resources entails drilling/mining further into these reserves. To facilitate this the parts of the distribution network close to these areas of acquisition must therefore physically expand (ie deeper mines, new oil wells etc).

Furthermore, it should also be remembered that the network links points of acquisition to end-use and so has the capacity to expand at both ends. An obvious example of physical network expansion to facilitate end-use would be the vast extent of growth in China. This growth has required the creation of vast swathes of new network infrastructure, including power grids, rail systems, road networks, shipping lanes, airports, and so on.

There is ample evidence that this process of expansion will continue in the future.

In fact we actually find it hard not to think of examples of the network expanding physically as new resources are accessed and new points of end-use are established. See for example BP’s Statistical Review of World Energy and Outlook to 2035 for further evidence: âĂć http://www.bp.com/en/global/corporate/about-bp/energy-economics/statistical-review-of-world-energy.html âĂć http://www.bp.com/en/global/corporate/about-bp/energy-economics/energy-outlook.html

"More directly, what is the authors’ estimate of the relevant length scale and how it has changed? Surely this must be a primary parameter of the analysis, and it might be interesting in its own right."

ESDD
6, C339–C345, 2015

We agree that the average length scale of the network of networks, L, is a very interesting quantity and, we argue, this increases as the system expands. Unfortunately, this is not a measured quantity, nor can it be at the global scale because the system is highly complex, irregular and heterogeneous.

"The transport network is nowhere close to space filling."

How does R3 know that? If R3 is referring to roads and railways (i.e. manned terrestrial transport) then these systems collect and distribute resources (including people) in space. Therefore they ARE space filling. If he/she means that there are lots of unfilled spaces then we refer him/her to our reply concerning the tree above.

"The ocean is basically empty with a handful of ships"

Please see our comment above referring to the “empty space” in the volume of air occupied by a tree. Ships are not networks, but the paths they take from port to port definitely are. As can be seen e.g. here:

(http://en.wikipedia.org/wiki/Ship_transport#/media/File:Shipping_routes_red_black.png)

these are ubiquitous over the oceans. But of course R3 is correct to infer that there is still a very considerable amount of empty space to explore and fill in the oceans with new shipping routes or expansions of current ones. This will only happen if there are resources that are economically attractive to be moved around. We might postulate that future exploitation of the mineral and energy resources on the ocean floor could become important and that at that time resource acquisition and distribution networks might expand in that direction.

"the skies are clear"

See e.g.:

http://en.wikipedia.org/wiki/Civil_aviation#/media/File:World-airline-routemap-2009.png

ESDD

6, C339–C345, 2015

"even road networks are far more space than road (this becomes a little dubious when one considers only urban areas, but this is a small part of the energy transport network). Electric cables are not packed into space, and neither are oil and gas pipelines limited by space. I simply don't see why the authors think that the space-filling network theory ought to apply even approximately in this situation."

Clearly R3 has misunderstood what is meant by a 'space filling' network in the literature. It is not the links in the network that fill space (even though they invariably have some space requirement). Networks are said to be space filling if they facilitate the occupation of space in some sense (c.f the tree). In the present context we refer to roads, railways etc. as space filling because they connect the spaces where resources are to the spaces where they are used.

"I think the authors need to work harder on explaining to the readership why this theory might be expected to be relevant."

With respect, R3 is the first of our reviewers and seminar audiences to have misunderstood what is meant by 'space filling' and hence been unable to make the obvious connection between this concept and the familiar understanding of the function of roads, railways, pipelines etc. The problem previous reviewers have with this concept is not that these networks are space filling (they agree that they clearly are), but that we argue that the space being filled appears to be three dimensional. This is why we dedicate an entire section of the manuscript to this issue.

"To a good approximation, I would expect the transport distance to simply be the great circle distance between resource extraction and use. Can the authors refute this naive assumption, either by theory or data?"

This is an incredibly simplistic view of the ways in which mass moves through industrial society. If one were simply concerned with, say, the movement of coal from Russia, Columbia or the USA to the UK, then, yes, we agree that the great circle distance between ports might give an approximate transport distance. But what about the in-

ESDD
6, C339–C345, 2015

credibly fine networks that transport coal from the seam deep underground to the port, and from the port to consumers, including millions of individual households? We believe that we do clearly refute this naïve assumption both empirically and theoretically.

"The dimension argument seems implausible and forced. In order for the network theory to apply, I believe it is the case that the expansion in all three dimensions must be at the same (at least, similar) proportional rate. Do the authors think this has happened? What are the quantitative implications, in relation to the horizontal length scale?"

If by “rate” you mean velocity, then no, we do not believe this. Firstly, optimal directed network theory does not relate to rates of expansion, it is a static theory. Secondly, the paper dedicates an entire section (4) to the issue of the dimensionality of the space filled by industrial society. With respect, we think, this indicates that R3 has not read section 4 properly. Rather than paste the two pages of text here that addresses this, we point R3 to the discussion in section 4 in answer to the question on this.

"So in summary, I do think there might be an interesting story here and I certainly don’t want to reject their ideas out of hand, but I do think the authors need to justify the conceptual basis of their analysis rather better than they have done so far."

It is heartening to read that R3 does not wish to reject our ideas out of hand! Unfortunately however, many of the comments that R3 has made are naïve or expose a poor understanding of the framework and evidence presented here. As always, we accept that we are fully to blame if we fail to clearly explain our ideas and arguments, even to a naïve or ill-informed reader, and hence we will take this opportunity to further refine our text in the hope that it is easier to follow our lines of argument.

Interactive comment on Earth Syst. Dynam. Discuss., 6, 133, 2015.