

Reply to comment

# The constructal law makes biology and economics be like physics

## Reply to comments on “The constructal law and the evolution of design in nature”

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Received 10 August 2011; accepted 18 August 2011

Available online 27 August 2011

Communicated by J. Fontanari

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**Keywords:** Constructal Law; Design in nature; Physics; Biology; Economics; Wealth

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We thank the authors of the Comments for their unanimously positive and constructive contributions to the discussion stimulated by the Constructal Law. The Comments reinforce the conclusion that the Constructal Law is the physics principle that unites the phenomena of design and evolution in nature, in both animate and inanimate systems.

With the Constructal Law, biology and economics become like physics—law-based, exact and predictable.

The “law of life” used by Prof. Basak [1] is a very good name for the Constructal Law. The concept of what it means to be alive is defined by the Constructal Law, and based on this definition “life” unites all the flow systems that morph freely as they evolve toward moving more easily on the landscape. The law of life unites the previously distinct realms of animate and inanimate systems, and the distinctly separate disciplines of Physics and Biology. Very timely is Prof. Basak’s review of Darwin’s five laws, and the fact that they are not laws in the physics sense because they are limited to biological systems. Also useful is his review of how the Constructal Law covers all forms of design in nature, including solid structures (the flow of stresses) and the design of hierarchy at all scales (organ sizes, and “the few large and many small” movement of everything on the landscape). His concluding question is a call to new and unbiased research with the Constructal Law.

Prof. Reis [2] contributes the physicist’s sharp view of what a law of physics is, and then evaluates the Constructal Law according to this standard. Especially clear is his presentation of the two laws of thermodynamics, and how the Constructal Law complements these laws. Also important is his observation that (like the laws of thermodynamics) the Constructal Law provides the foundations of both natural and engineered design. Many of us tend to overlook the

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DOI of original article: [10.1016/j.plrev.2011.05.010](https://doi.org/10.1016/j.plrev.2011.05.010).

DOI of comments: [10.1016/j.plrev.2011.07.001](https://doi.org/10.1016/j.plrev.2011.07.001), [10.1016/j.plrev.2011.07.007](https://doi.org/10.1016/j.plrev.2011.07.007), [10.1016/j.plrev.2011.07.002](https://doi.org/10.1016/j.plrev.2011.07.002), [10.1016/j.plrev.2011.07.003](https://doi.org/10.1016/j.plrev.2011.07.003), [10.1016/j.plrev.2011.07.005](https://doi.org/10.1016/j.plrev.2011.07.005), [10.1016/j.plrev.2011.08.002](https://doi.org/10.1016/j.plrev.2011.08.002), [10.1016/j.plrev.2011.08.003](https://doi.org/10.1016/j.plrev.2011.08.003), [10.1016/j.plrev.2011.07.004](https://doi.org/10.1016/j.plrev.2011.07.004), [10.1016/j.plrev.2011.07.006](https://doi.org/10.1016/j.plrev.2011.07.006).

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fact that humans and human society are both system and environment in “design in nature” in general. Prof. Reis’ article is a cogent reminder of who we are and why we fit.

“Go with the flow” is an excellent mental viewing that Dr. Tuhtan [3] employs for uniting under the Constructal Law the design of hydropower and the design of the animal habitat. His article opens our eyes to the hand-in-glove design of the system and its environment—both morphing, evolving, and flowing more easily in time. His observations on the evolution of weight-normalized metabolism in big history add support to the evolutionary design driven by the Constructal Law (e.g. Figs. 6 and 7 in our article). Coincidentally, similar to Prof. Basak’s bridge between physics and biology is Dr. Tuhtan’s constructal-law bridge, “across the lonely divide which often isolates physicists from ecologists (and) engineers from biologists”. Bridges and connections are the new bricks and mortar of the new, better and more compact science. This is why Dr. Tuhtan’s concluding remarks on the role of the Constructal Law in science education, for the benefit of young scientists, are worthy of note.

Prof. Miguel [4] strengthens the physics reach of the Constructal Law with examples of inanimate and animate pattern and rhythm, and with a review of why the first and second laws of thermodynamics do not account for such phenomena. Most interesting are his examples and references that deal with the constructal design of social organization, which ranges from bacterial colonies to corals, pedestrian movement and the economic development (the wealth) of countries and territories. This is a very fruitful direction in which to discover and practice design based on the constructal law.

Profs. Lorenzini and Biserni [5] note the breadth of the territory covered by advances with the Constructal Law—from biology and physics to social dynamics and economics. They highlight “wealth” as a new concept in physics, which is recommended by the relation between economic activity (GDP) and fuel consumption, which means the movement of people, goods and communications on the landscape.

Prof. Ventikos [6] draws attention to the central role that the Constructal Law plays in medicine and biomedical engineering. This design principle of physics serves as guide for new research on vascular growth, controlled growth and regenerative medicine. The vascular design emerges necessarily because diffusion alone has a limited range for delivering nutrients and oxygen to living cells and tissues. The principle governs how the channels are combined with the diffusive interstices in order to bathe the living body most effectively. This two-mechanism design is better than a single mechanism, and it governs the tapestry of movement at all scales, including river basins and urban traffic. The long and fast (channels) are designed hand in glove with the short and slow (diffusion).

Prof. Wang [7] draws with sharp lines the contrast between the Constructal Law as a law of physics and the many ad-hoc approaches that describe empirically the phenomena of design in nature. He also distinguishes the Constructal Law from the first law and the second law of thermodynamics. His observations are very important, especially today when the growth of science tends to obscure what is a law, and what is prediction and not description.

Prof. Meyer [8] reminds us of the importance of simple theory. This is particularly important in science education, because this is the direction in which science itself evolves to become better, more accessible and easier to teach. He then brings up the challenging topic of “design”, the difficulties of teaching it in the absence of a scientific principle, and the timely arrival of the Constructal Law to answer this need. The new references of novel engineering applications guided by the Constructal Law are very useful to this group review effort in this field.

More applications and references are offered by Prof. Rocha [9], who reminds us that the natural growth of the field is also reflected in the emergence of spontaneous annual conferences devoted to the Constructal Law. This natural phenomenon of conference emergence, like the new terms, connections and references offered in these commentaries, is the constructal path to a more powerful science that accounts for the phenomenon of design in nature, and makes it accessible to the widest audience [10–12].

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