**Global Economic Networks:**

**Tracking Material Flows and Money Flows, Downstream As Well As Upstream**

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**Abstract:**

Manufacturers are concerned with the reliability of their supply chains and thus with the networks by which they receive the inputs on which they depend. For example, producers of computers sold in one country will be interested in secure sources of gold and rare earth metals embodied in the chips they require, even though they generally depend only indirectly on these resources. At the same time the extraction industries want to understand the patterns of demand for their output as it is used to produce intermediate and consumer goods fabricated and sold globally, to both direct and indirect customers for their resources. The first case involves tracking upstream from the computers to quantify the embodied gold originating in one or several regional sources; the second case requires tracking downstream from the resource deliveries through production of intermediate products to the final good or goods. Of course, the quantity of Peruvian gold embodied in computers sold in the US will be the same in both cases as they involve traversing the same network of nodes but in different directions. In this sense the upstream flows can be considered the *dual* of the downstream flows. However, that particular network – linking Peruvian gold to US computers -- is only *one layer* of *one sub-network* of the much more extensive, and deeper (i.e., many-layered), global network of all economic flows that we propose to analyze. For any two nodes in that sub-network, say Peruvian gold and Japanese computer chips, the flow between them that ends with computers sold in the US is only a portion of the total flow between these two nodes, since other flows end up embodied in, say, telephones sold in China. It is in this sense that the flow between any two nodes is the sum of many layers of flows.

Another, and the more familiar, conception of duality in input-output economics is that between the primal or quantity relations, describing the flows of resources and goods among sectors and regions, and the dual or price relations that quantify the flows of payments (money) for final goods, intermediate goods, and resources. Each flow (arc) in the full global economic network, or in any constituent sub-network, can be measured in a quantity unit (such as tons) or in the corresponding money unit (measured, e.g., in dollars). A downstream question in the context of the payment network is to determine how much of each dollar paid for computers by consumers in the United States is received, after flowing through the network of intermediate products in different economies, by miners of gold in Peru, or by all miners of gold anywhere, or by owners of all factors of production in Peru. Upstream questions involve determining the sources, in payments for consumer goods in different economies, of the earnings of these miners or owners of other factors of production.

The objective of this paper is to demonstrate the conceptual overlap, and the conceptual distinctiveness, among these four concepts of the global economic network by presenting the algebra for answering the four kinds of questions, illustrated by numerical examples. Structural Path Analysis (SPA) is widely used to quantify upstream flows, typically in the case of input-output databases quantified in money values, where each such value is the product of a quantity and a unit price. We supplement the SPA upstream approach by absorbing Markov chain (AMC) frameworks, which can be developed to track both material flows and price flows, and to do so in the downstream direction. A key motivation for developing the downstream payment network is to apply it to the results of scenarios about the future (developed in papers by the authors and colleagues) to examine the likely magnitudes of wage payments to workers, profits to owners of capital, and both normal payments and scarcity rents to those with property rights to resources in different parts of the world economy. This is important because the scenario analyses we have conducted lead us to believe that there may be substantial shifts in the future global distribution of income as factors such as fresh water and arable land become increasingly scarce.