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The trophic theory of money: principles, corollaries, and policy implications

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Abstract

Perhaps the greatest controversy in sustainability science is whether GDP is a reliable indicator of environmental impact. Yet the trophic structure of the human economy is such that GDP — in concert with real money supplies — is an excellent indicator of biodiversity loss, pollution, ecological footprint, and other aspects of environmental impact. The trophic structure of the human economy reflects that of the economy of nature, where producers (i.e., plants) support primary consumers (herbivores), which support secondary consumers (omnivores and predators) and service providers (e.g., scavengers). In the human economy producers (i.e., farmers) support primary consumers (heavy manufacturing), which support secondary consumers (light manufacturing) and service providers (e.g., transportation). The annual amount of human economic activity — GDP — is measured with monetary flows of expenditure and income. The trophic theory of money is that money originates via the agricultural surplus that frees the hands for the division of labour unto manufacturing and service sectors, and therefore reflects the environmental impact of human activity. The primary corollary is that the quantity of money — and GDP — indicates the amount of agricultural surplus and related activity at the trophic base of the economy (i.e., mining, logging, commercial fishing and other extractive activity) and the environmental impact of such activity. Inflation, technological progress (a function of GDP), and international trade affect the precise relationship of real money supplies to environmental impact in any given country, without affecting the underlying trophics. Purely financial activity, such as speculation in derivatives, does not affect GDP or real money supplies.

Keywords: agriculture, environmental impact, GDP, money, trophic levels

The trophic theory of money: principles and policy implications

Perhaps the greatest disagreement in sustainability science and policy stems from the question: Does GDP invariably indicate environmental impact? Some say yes it must, while others adamantly say no, but a great many respondents neither proffer nor accept anything definitive. Their general sense seems to be that GDP has indicated environmental impact, ever since its measure was taken (1934 in the USA), but that, theoretically, if the economy was structured a "new" way and incorporated certain technologies, GDP could grow without concomitant increases in throughput and/or environmental impact.

The trophic theory of money is that, due to the fundamental, ecological structure of the human economy, real GDP (and real money supplies) must indicate environmental impact, invariably and inevitably. This is the theory of money most congruent with the biological sciences. It helps to delineate the paradigm of sustainability science from that of conventional economics.

In order to explain the trophic theory of money I will here summarise: 1) the concept

of trophic levels in nature; 2) the trophic structure of the human economy; 3) why the trophic structure of the human economy entails a particular theory of money, and; 4) precepts and corollaries of the trophic theory of money. I will conclude by exploring some implications of the trophic theory of money for sustainability science and public policy.

Trophic levels in the economy of nature

The word "trophic" is defined as "of or relating to nutrition" (Merriam-Webster online dictionary) and connotes especially the energy derived from food. The word is seldom used outside of the ecological sciences, where it is almost invariably coupled with the noun "level." A trophic level is a set of species that occupy a similar position with regard to the flow of energy (derived from feeding) in the economy of nature (Ricklefs and Miller 2000). The concept of trophic levels is used to summarise two major fields of ecological study: the energy pathways associated with the sustenance of species, and the relative biomass of major categories of species.

A typical ecosystem has three basic trophic levels: producers, primary consumers, and higher-level consumers (Fig.1). The producers are plants, which produce their own food through the process of photosynthesis. The photosynthetic growth of plants is called "primary production."

All animal life depends on the plant community for nutrition. Some animals eat plants directly; these are the primary consumers. Higher-level consumers eat primary consumers. Finer distinctions among higher-level consumers are uncommon and not usually dealt with in terms of trophic levels, but rather in the more detailed terms of food webs and energy pathway diagrams.

The primary consumers are also called "herbivores." Consumers at secondary or higher levels are "predators." However, many if not most predators supplement their diets with plants; enough such supplementation warrants the label "omnivore." *Homo sapiens* is a classic omnivore (Pollan 2006).

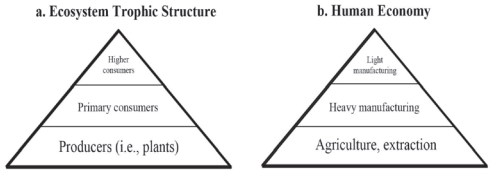

Figure 1: Trophic structure of: (a) economy of nature and (b) human economy (from Czech 2013).

Although the basic trophic levels comprising the economy of nature are simple to understand, it can be challenging to categorise particular species. A fox living in one ecosystem, or at a particular time of year, or at a particular age, may subsist primarily on plant materials (as with a primary consumer), while a fox in different circumstances may subsist primarily on small animals (as with a secondary consumer). Few ecologists would classify a fox as a primary consumer, however. Taken as a whole, fox species — as well as most other canids — are classified as predators that happen to be somewhat omnivorous.

Some species are not readily categorised into trophic levels. Scavengers, for example, are neither plant eaters nor predators most of the time. Yet they do eat primarily animal tissue, so are categorised as secondary consumers in trophic terms. The fact that they "clean up" the ecosystem of rotting flesh leads us to also call them, somewhat anthropomorphically, "service providers." Numerous other services are performed in the economy

of nature such as pollination, decomposition, and the provision of hiding or thermal cover. As members of the economy of nature, service providers may be designated in the trophic structure as necessarily interacting with the "regular" members. Their lives of service would not be sustained without the other species and, as with the regular consumers, they are ultimately dependent upon the photosynthetic activity of plants.

Trophic structure of the human economy

As emphasised in ecological economics and sustainability studies, the human economy is a subset of the economy of nature. In terms of trophic levels, which theoretically range up to 5.5 for large carnivores, human trophic levels range from approximately 2.04–2.57 (Bonhommeau et al. 2013), reflecting not only an omnivorous tendency but substantial variation among cultures. Yet humans also occupy and dominate the apex of the trophic structure in the sense of consuming virtually every other species that is edible, palatable, and economical to harvest (Czech 2000, Roopnarine 2014). These species include numerous highly predaceous fish, reptiles, and mammals, many of which are systematically harvested in various cultures. Conversely, only in extremely rare instances do nonhumans hunt and consume humans.

As a mammalian species, *Homo sapiens* follows the same natural laws that apply to the other species in the economy of nature. In addition to residing in the trophic structure, humans must abide by the laws of thermodynamics and the principles of ecology. What distinguishes humans most, in ecological terms, is the breadth of the human niche, which reflects the unique mental and physical capabilities of *Homo sapiens* (Kingdon 1993).

The human niche is so broad — human activities are so variable — that the human economy itself has a well-developed trophic structure (Fig.1). Farmers are the producers. As with the plants in the economy of nature, farmers produce their own food, and their surplus production is then available for consumers. This was emphasised by the 18th-century French physiocrat, Francois Quesnay, in the Tableau Economique.

However, within the human economy, most members do not make their living by literally eating the members of lower trophic levels. The "living" made by humans goes far beyond mere feeding to encompass the production and consumption of a great diversity of goods and services, and we may also include loggers, miners, ranchers, oilmen, and fishermen as "producers" in the human economy. Each of them "produces" goods needed by themselves and others in the human economy, although technically they extract such goods directly from stocks of natural capital such as timber, minerals, and forage. Farmers still come closest to being true producers — in the physiocratic and ecological sense — because instead of extracting per se, they participate closely with the process of photosynthesis, the ultimate production process for life on Earth.

Manufacturers use raw materials extracted by the producers to manufacture goods. They range from a heavy manufacturing base (such as mineral refining) up through the trophic pyramid to the lightest manufacturing sectors (e.g., computer chip manufacturing) (Fig. 1). Heavy manufacturing requires the rawest of materials, whereas much of the light manufacturing is performed with refined or manufactured materials flowing from lower in the trophic structure.

As in the economy of nature, service sectors in the human economy are not readily placed in particular trophic levels. Cashiers, cab drivers, janitors and other service providers do not produce or consume in a systematic fashion that proceeds upward from one trophic level to the next. A truck driver may deliver a load of logs from forest to sawmill one day, and a load of lumber from sawmill to farm the next. The banker may lend to the farmer or the capitalist. Professional athletes entertain farmers, industrialists, and bankers. Each contributes in some way to GDP, yet none would contribute in any way without the producers, as there would be no one to service.

A theory of money for sustainability science

There is no authoritative source for establishing precisely what is required of a theory of money, but myriad "theories" have been proffered pertaining to the following questions:

- How does money originate?
- How does the quantity of money relate to the quantity of real economic output?
- How is the quantity of money related to prices?
- What influences the velocity of money in circulation?
- What is the proper authority over money supplies and other monetary policy?

The trophic theory of money is primarily concerned with the first question: the origins of money. This is an appropriate question to prioritise, for, as Aristotle said, "He who thus considers things in their first growth and origin … will obtain the clearest view of them" (Aristotle 2008:26). Indeed, the view we get from a trophic perspective provides insights to several of the other issues as well, and goes beyond to address the question at the heart of this paper: Do GDP and money supplies invariably indicate environmental impact?

The trophic theory of money is that money originates as a matter of agricultural surplus, and that the generation or flow of real money ("real" meaning adjusted for inflation) is a real measure of — not just a variable affecting — economic output. The trophic theory of money also posits that the quantity of real money — and/or economic output as measured by GDP — must indicate environmental impact, including biodiversity loss, pollution, and ecological footprint. We can go so far as to posit that GDP is such a fundamental, reliable indicator of environmental impact that it may be considered a "measure" per se. In this sense, GDP is analogous to the volume of engine displacement, which is such a reliable indicator of horsepower that it has overtaken that somewhat esoteric measure. Engine displacement offers the substantial advantages of being easy to measure and being one of the specifications ("specs") invariably provided with the product. With such advantages, few people are required or compelled to purchase an expensive and cumbersome dynamometer to measure horsepower per se.

Unlike engine displacement, GDP is not necessarily easy or simple to measure. However, calculating GDP is relatively straightforward given the principles of national income accounting, including the fundamental identity thereof: Production = Income = Expenditure (Lequiller and Blades 2014). More importantly, GDP is carefully and consistently measured pursuant to the policies and procedures of the U.S. Bureau

of Economic Analysis (and by analogous bureaus in other countries). It is an already available "spec" that, if indeed a reliable measure of environmental impact, makes it largely unnecessary to develop alternative, costly, and cumbersome metrics.

The trophic theory of money suggests that GDP may be viewed as "the" measure of environmental impact — especially in aggregate contexts such as the environmental impact of a nation — more than any other single indicator of environmental impact per se. A natural corollary is that the quantity of money is a negative indicator of sustainability.

The origins of money — trophic and historical

Money may be defined as anything that functions in society as a medium of exchange, unit of account, and store of value (Davies 2002). In the scholarly literature many commodities are cited as historic forms of "money," but Seaford (1994) insisted that, to qualify as money per se, the item in question must be the exclusive medium of exchange (and unit of account, and store of value). This qualification rules out the vast majority of barter commodities that preceded minted coins and paper currency. Therefore these barter commodities, when portrayed as "money," are usually done so with the qualifier "commodity." In societies with enough surplus and division of labour to barter, long periods of using commodity money nearly always preceded the use of money per se (Weatherford 1997).

The phrase "origins of money" connotes these conceptual, historical, and linguistic considerations of money. Sometimes the phrase is used in discussions of who or what actually creates the physical money per se — as in the printing of bills or the minting of coins — and who authorises its creation. Although this issue is relevant to ecological economics, particularly the theme of wealth distribution, it is not our concern with the trophic theory of money.

Another use of the phrase "origins of money" is in historical or evolutionary context, where the line of inquiry is, "When was money first used, and how did such usage come about?" The trophic theory of money has much to offer in this context, as we will see.

However, with the trophic theory, "origins" is also used in a more fundamental, ecological, and ontological sense. Just as the laws of thermodynamics are more fundamental than conventional economic "laws" pertaining to the real sector (Say's Law, for example), trophic theory is more fundamental — more grounded in the natural sciences and first principles — than conventional economic theories pertaining to the monetary sector. In fact, trophic theory itself rests on a solid foundation of thermodynamics. Put in plainest terms, trophic theory may be summarised as: You can't get something from nothing (first law of thermodynamics), and you can never achieve 100% efficiency in the production of biomass (second law of thermodynamics). Therefore, of all the theories of money, the trophic theory of money is most congruent with the natural sciences.

Agricultural surplus and the origins of money

Why does real money originate as a matter of agricultural surplus? In the simplest of terms, because without agricultural surplus there is no division of labour, and neither the need nor even the opportunity to develop a monetary system. In fact, given the trophic theory of money, one would expect the following, and only in the following order:

1. development of agriculture, successful enough for ongoing surplus production
2. division of labour into numerous agricultural and non-agricultural pursuits
3. development of a money supply and system (almost invariably preceded by widespread bartering and proto-money)

Adam Smith briefly alluded to this natural sequence in Chapter 4 of the *Wealth of Nations*, and likely his study of Quesnay's Tableau guided his thinking (Czech 2013).[1] The sequence seems to emanate a certain cultural and political orderliness, but more fundamentally is pre-ordained by ecological reality. Any other sequence of the three stages is virtually prohibited by the principles of ecology. The evolution of the human trophic structure, starting with agricultural surplus, is what makes money a meaningful concept and "authorises" the development of a monetary system.

The development and use of money in the absence of agricultural surplus is so inconceivable and nonsensical that it evidently never occurred in the long arc of human evolution. As Ferguson (2008:20) observed, "Hunter-gatherers do not trade … Nor do they save, consuming their food as and when they find it. They therefore have no need of money." That is a bit of an oversimplification, but if money was used in pre-agricultural settings, it was so limited in scope and functionality as to go undocumented in the archeological record. Furthermore, it would have occurred where some other form of food surplus was relatively widespread and long lasting; i.e., under conditions highly analogous to agricultural surplus per se. Shell, for example — most notably cowry — was first used as commodity money in coastal societies (Davies 2002). Given the trophic theory of money, we readily note that fish harvesting must have been sufficiently productive in these circumstances as to be analogous to agricultural surplus, and this indeed is borne out in the archeological literature (Kingdon 1993). It is no coincidence, then, that widespread, long-lasting, systematic use of money — certainly coinage — did not occur prior to the domestication of plants and the development of agricultural crops during the Neolithic Revolution.

Similarly, it is no coincidence that money is not known to have circulated far outside areas of agricultural surplus during the Neolithic Period. This may come as a surprise to some, because misinformation on this topic is prevalent. For example, a stylish article, "When — and why — did people first start to use money" (Kusimba 2017) appears in the "Science and Technology" section of The Conversation (an online journal advertising its "academic rigor" in its subtitle). Kusimba's (2017) article will be one of the first articles located using internet search engines and the search phrase, "first use of money," and its second sentence provides "…the history of human beings using cash currency does go back a long time — 40,000 years." This astonishing claim is undermined a mere six paragraphs further, where we are reminded of the closest thing to consensus in numismatics, "The Mesopotamian shekel — the first known form of currency — emerged nearly 5,000 years ago." Nothing in the article remotely supports the notion of "cash currency" at any time during the Paleolithic Period (i.e., the "Stone Ages" including 40,000 BP). Rather, there is only mention

[1] Quesnay, it should be noted, was a Renaissance man in the king's court of post-Renaissance France, and was especially an expert in agricultural production and economics.

of bartering for "flint weapons and other tools" among hunters.

The trophic theory of money provides an ecologically rich explanation for the transition from barter through "commodity money" to money per se. The development of a thorough, economic trophic structure including a diversity of manufacturing sectors from heavy to light — and supporting a diversity of service sectors — is essentially the story of human evolution from hunter/gatherers to modern actors in the industrial and computerised economy (Kingdon 1993). The intermediate ages of transition from hunting/gathering to widespread agricultural surplus brought to a certain fruition the producer trophic level and set the stage for divisions of labour, both within the producer level (including unto the many extractive trades and specialties) and beyond to manufacturing and services.

This transition did not occur overnight — indeed it comprised "ages" — which explains why there was such a lengthy, hard-to-delineate transition from barter to money per se, which did evidently span the ages from approximately 40,000–5,000 BP.

The gradual nature of this transition is reflected in the best-documented examples of commodity money (Table 1). Shell was noted above; its commodity value was primarily as jewelry. The shell of *Cypraea moneta* ("money cowry") in particular, was durable, convenient, recogniisable, and divisible, so it was naturally selected as currency (Van Damme 2007). The use of shell lasted so long, it hasn't entirely died out on the Indonesian archipelago.

Some scholars have considered cattle in herding societies to be the first form of "money," yet cattle "cannot be properly considered as money because, being such a 'heavy' or expensive unit of account and standard of value, they were not very suited to performing the other more mobile functions of being a good means of payment and medium of exchange, which apparently demanded something much smaller than, say, a cow" (Davies 2002:42). As Davies (2002) pointed out, cattle are more accurately designated as an early form of working capital. As with shell in coastal economies, however, the use of cattle in exchange would hardly be an exception to the trophic theory of money, because surplus cattle in pastoralist cultures were analogous to crop surplus in agrarian cultures.

Non-necessity of money

The trophic theory of money does not imply that agricultural surplus must result in the use of money; only that the use of money is predicated upon agricultural surplus. There were evidently ancient cultures — perhaps most famously Mayans and Aztecs — who developed relatively long-lasting agricultural surpluses and yet never developed monetary systems with exclusive currencies (Table 1).

Even the Mayans, though, used cacao beans and greenstone beads as common means of exchange (Sharer 2009). Furthermore, it seems likely the Mayans would have developed a monetary system if not for their mysterious demise (circa 800-900 AD) and later devastation by the Spanish. With their use of beans and beads, the Mayans were clearly on the brink of using money per se, but then evidently exceeded their ecological capacity, a process exacerbated by a devastating drought (Diamond 2005). The population declined sharply and Mayans retreated into peasantry, with very little surplus or division of labour. Some Native American tribes in North America, especially in the ecologically productive river valleys of the

Table 1. Origins of agriculture and money; highlights of well-documented and widespread scenarios. All dates Before Present (i.e., years before 1950 AD)

Neolithic Region	**Origins of Agriculture**	**Commodity Money**	**Money Per Se**
Mesopotamia	10,000-9000 (especially barley; Jones 1952	Pre-3100, barley grains (Powell 1996)	5000-2500, silver shekels (Powell 1996)
Ancient Greece (including Lydia)	9300-9000 (Halstead 1996)	≥3000, oxen (Mundell 2002)	2490-2480, Lydian coins of electrum (a gold and silver alloy; Weatherford 1997)
China – Yellow River Basin	≥7450 (most notably millet; Crawford et al. 2005)	3950-1950, cowrie shell and imitations, knife and spade proto-money (Yang 2011)	≥2170, copper coins (Smith 1926)
Ethiopia	~ 7000 (Ehret 1979)	≥1200, salt blocks, "amole tchew"	250-150, Maria Theresa thalers
Mesoamerica	6000-4000 (most notably corn and beans; Johannessen and Hastorf 1994)	2000-900, cacao beans, quachtli (cotton cloaks), beads, shells (Sharer 2009, Weatherford 1997)	No money per se among ancient Aztecs and Mayans.

https://blog.continentalcurrency.ca/ethiopian-birr/ https://en.wikipedia.org/wiki/Ethiopian_birr

East, produced large agricultural surpluses (most notably with the "three sisters" of corn, beans, and squash) and developed complex economic societies (Stannard 1992, Park et al. 2016). Prior to European contact they used wampumpeag, or "wampum," as a means of exchange (Davies 2002). Wampum — most commonly from the widespread freshwater clam *Venus mercenaria* — had some medicinal value, being useful in the stopping of nosebleed (Francis 1986). It was kept as beads and accumulated in strings, and was therefore readily stored in various quantities, including common amounts often used in exchange (analogous, for example, to ten-dollar bills today).

As with the Mayans, some of the North American tribes were on the verge of using money per se. However, conquest by Europeans, and more importantly widespread smallpox, decimated many tribes and severely impacted the rest (Stannard 1992). While the earliest colonists apparently used wampum and Native American commodities as often as English coinage, distinctly "American" forms of money developed rapidly as the great expanse of rich American ecosystems was highly conducive to agricultural surplus and wide open for business in multiple trophic levels, having been vacated by the smallpox-ridden tribes. Wampum was eclipsed by pieces of eight (Spanish *reales*), New England schillings, revolutionary "continentals," Civil War "greenbacks," and finally dollars and cents.

As Weatherford (1997:59) postulated,

> Prior to the invention of money in the form of coins, the chapters of history overflow with stories of many civilisations on different continents speaking different languages and worshiping different gods, but

> we see in virtually all of them a common pattern. Whether we consider the ancient Egyptians or the Aztecs, the Hittites or the Babylonians, the Cretans or the mysterious people of Mohenjo-Daro, we see that they all appear to have risen only to a similar level of civilisation. It is almost as though each of them encountered the same invisible wall, which they were unable to penetrate. They developed their own architecture and religion, science and commerce, poetry and music only so far before they stagnated. The Greeks, however, broke through this barrier. Suddenly, architecture, philosophy, science, literature, and the other arts and sciences soared to a level of attainment unknown to any earlier civilisation. Some scholars would have us believe that this breakthrough arose from some superior quality of the Greek mind, psyche, race, or culture…

Weatherford went on to ascribe the "breakthrough" to the Greeks' proximity to Lydia, where the first known coins were minted (Table 1). In his opinion, the Greeks took the Lydian invention and brought it to new heights, along with all the activities it was exchanged for.

No doubt the availability of a widely accepted, easily accounted, and durable means of exchange allowed for efficient, swift transaction. In a sense, a reliable currency reduced transaction costs, as economic actors of all kinds could quickly exchange their goods and services and get on with life (including production and consumption of more goods and services), rather than struggling to measure, agree upon, or even recognise the various forms of proto-money. It was as if the adoption of currency lifted an unspecified tax previously inflicting Greek society.

That said, given the trophic theory of money, Weatherford's attribution to money of such a profound "breakthrough" in Greek civilisation is unfounded. There was no "invisible wall" mysteriously preventing the Greeks from flourishing. Rather, they shared a common ancient history with other peoples who underwent the long gradual process of agriculture. It was their eventual achievement of substantial surplus that allowed for significant division of labour as well as for the use of money in exchanging the fruits of their labour.

It is somewhat remarkable that the Greeks did not have the benefit of a "breadbasket" such as the American plains or Ukrainian steppes. On the other hand they did benefit tremendously from a Mediterranean climate and diverse ecosystems superior for agricultural (and pastoral) purposes to those of the Mayans, for example. Meanwhile abundant coastline allowed them to supplement their terrestrial production with protein and fat intake from fish. Furthermore, there is nothing about the trophic theory of money to deny the relevance of raiding, warfare, and eventually regional trade to increasing food surpluses and trophic development. The long history of Greek warfare — largely successful prior to the Roman Empire — brought with it the spoils of war, including Persian goods. These goods added to what the Greeks produced themselves and had the effect of increasing Greek agricultural surplus, freeing the hands for a further division of labour and the exchanging of additional money.

Agricultural surplus and the quantity of money

If the origins of money are in agricultural surplus pursuant to the trophic theory of money, then it is not far-fetched to hypothesise that the quantity of money — and/or the level

of GDP — is proportional to agricultural surplus. There is in fact plenty of evidence to support this hypothesis. The shekel, for example, originated as literally 180 grains (or "she") of barley (Acton and Goldblatt 2010). One can hardly find a better example of money supplies tracking with agricultural surplus! (Barley reserved for exchange, and therefore not consumed as food, represents a surplus.) The salient point, though, is that the grain of barley could have instead been a gram of silver, nickel, or lead. Although each of these metals was also useful as a commodity, none would have been useful as money per se if the barley (and other food) surplus hadn't allowed for the division of labour and the subsequent exchange of goods and services.

Indeed shekels evolved to become measures of barley in terms of silver equivalent. The weight of the original shekel (i.e., the she of barley) became the weight in silver that was worth one gur (a type of container, hauled on an ass) of barley. In other words, a gur of barley cost a silver shekel, and vice versa (Cripps 2017). Evidently for much of Mesopotamian civilisation, as documented most assiduously in Assyrian cuneiform bookkeeping, this was the case, and these units of barley and silver comprised the primary forms of Mesopotamian proto-money (Cripps 2017). Ultimately, however, barley gave way to minted silver coins — money per se — if for no other reason than coins were far more durable as a store of value. This giving way to silver coins also hints at increasing agriculture surplus, because there is little need for durable storage when grain surplus is a year-to-year concern.

Another indicator of agricultural surplus highly relevant to the trophic theory of money is the percentage of farmers in society. This indicator of surplus is straightforward. If it takes one farmer to support two individuals (including the one farmer), we have 50% farmers, and little demand for exchange. Money is extremely unlikely to originate in such a scenario, although it might be used to some extent if it flows in from adjacent regions where agricultural surplus is high. (Money might also originate if the small surplus is predictable and reliable for lengthy periods of time, but that is notoriously rare in agriculture). Conversely, if one farmer supports 10 economic actors, we have 10% farmers, and palpable demand for exchange. Money is likely to originate in such a scenario; alternatively, if money circulates in adjacent regions, it is likely to be adopted.

As a variable affecting the origins of money and money supplies, the percentage of farmers offers insight into why the Mayans never quite "advanced" to the stage of money per se. As Diamond (2005:164) described, "At least 70% of Maya society consisted of peasants… because Maya agriculture suffered from several limitations." These limitations included low yields, low protein production, and difficulty storing crops due to a humid climate. Each of these limitations would have precluded substantial division of labour or the development of a thorough trophic structure. What little division of labour occurred was primarily into soldiering and slavery (for serving soldiers and nobility).

In sharp contrast is the modern United States, where farmers comprise approximately 2% of the population and each farmer can feed "on the average 125 other people" including Americans and among foreign trading partners (Diamond 2005:164). This is a level of agricultural surplus capable of supporting a thorough and rich (in several ways) trophic structure, conducive to a

tremendous amount of exchange, which in turn calls for a means thereof; i.e., money.

Agriculture, money, and environmental impact

Pursuant to the trophic theory of money, the human economy — the size of which is measured by GDP — proliferates in proportion to agricultural surplus. Meanwhile agriculture has environmental impacts (Bodley 2012). Primitive agriculture would have had slight impact, but as agriculture intensified toward the levels required for divisions of labour — and the use of money — so too did its impact. Mesopotamia again provides an early example. The amount of barley (proto-money) cultivated in Mesopotamia — the "land between the rivers" — was a function of the amount of land irrigated along the Tigris and Euphrates Rivers and tributaries. But as Bodley (2012:52) described, "There is clear evidence that intensive agricultural practices in ancient Mesopotamia, where irrigation causes the gradual accumulation of salts in the soil, were also contributing factors in the fall of Sumerian civilisation after 2000 [BC]."

Obviously, too, the mining of silver and gold has pronounced environmental impacts. The fact that these metals have long been the primary metals used in coinage is symbolic of the fact that all extractive activities near the base of the economic trophic structure have a heavy footprint on the environment. Yet the obviousness of these impacts should not obscure the effects of all economic sectors throughout the trophic structure of the human economy. All sectors have direct environmental effects, but more profoundly, all are portions of an economy that grows as an integrated whole. Due to the tremendous breadth of the human niche, this trophically structured economy grows at the competitive exclusion of non-human species in the aggregate (Czech et al. 2000). The staggering loss of biodiversity is perhaps the greatest indicator of environmental impact (Wilson 2017).

Indeed most if not all the areas associated with the early use of money are also associated with early episodes of ecological degradation and limits to growth. For example, the Yellow River Basin is the "cradle of Chinese civilisation" (Feng et al. 2006:125) where Chinese agriculture and money originated. There, too, millennia of trophic buildup have led to an environmental crisis of equally historic proportions. It is no coincidence that the Loess Plateau (along the Yellow River) is the first region identified in assessments of Chinese environmental history (see for example Maohong 2004). The plateau "had been over-cultivated and overgrazed, resulting in soil erosion and a criss-cross network of gullies, following the development of civilisation in the Yellow River valley" (Maohong 2004:480).

Circular flow of money

In conventional economics and business textbooks, the economy is often modeled as a circular flow of money, with factors of production flowing in one direction and payments thereto in the other. In circular flow diagrams, the factors of production are often limited to labour *L* and capital *K*. Money certainly does flow between labour and capital. Capital pays wages; labour turns around and purchases from capital, and there is an obvious circularity to the process.

Unfortunately the circular flow of money depicted in textbooks typically leaves out the ecological context, as well as a crucial factor of production. While the circular flow displays labour and capital as the factors of production, it typically leaves out land, which is at once an essential factor of production and a boundary within which labour

and capital must operate. This omission is wholly conducive to the broader neoclassical propensity to ignore limits to growth. In a sense, the omission reflects the "landless production function" of output $Y = f\{K,L\}$ (Czech 2013:158). With the circular flow of money and the landless production function in mind, the student can hardly avoid envisioning the economy growing outward into boundless space.

The trophic theory of money alleviates this problem because merely including money in the circular flow diagram accounts for agricultural surplus and environmental impact. With the trophic theory of money, the circular flow can hardly be considered without recognising limits to growth. The circular flow suddenly becomes a demonstration of how money cannot become unhitched from the real economy. It must indeed reflect the flows between capital and labour. These entities are readily recognised as actors in the trophic structure of the real economy. If the trophic structure is not more heavily drawn upon (i.e., without additional surplus at the agricultural base), the injection of more money fails to reflect what is happening in the real economy. Instead, it is simply an episode of inflation.

Money, GDP, and finance

It is a common misunderstanding outside the world of monetary policy and national income accounting that the traffic in recent years of financial products such as rainbow derivatives with iron butterfly options purchased online, perhaps even with Bitcoin, somehow represents a "new economy." This misunderstanding, which even afflicts environmental and ecological economics, readily morphs into the notion that we live in an "information economy" unrooted or decoupled from biophysical throughput. In reality financial speculation itself has no effect on GDP or real money supplies, although it is suspected of having an effect on nominal GDP (Sipko 2011).

Speculation itself should not be confused with the services of the brokers, agents and bankers who earn an income for assisting customers fulfill their speculations. This distinction — service vs speculation — helps clarify the real nature of GDP. Speculation is similar to gambling whereby the speculator "bets" (presumably with some analytical insight) on the chances of particular trends in interest rates, stock prices, insurance claims, and a wide variety of other financial data. Nothing in the trophic structure of the economy is produced or consumed in the act of speculation. However, the placing of bets requires transacting, recording, and accounting, performed by brokers, agents and bankers. These are real people using real energy and material (e.g., office equipment and supplies) to provide a real service accounted for in GDP. The key point, vis-à-vis the trophic theory of money, is that none of the brokers, agents or bankers would be operating in the absence of agricultural surplus. Their income required real surplus at the trophic base of the economy.

Perhaps an even better example is of gambling per se. If a gambler "spends" a million dollars at a casino and returns with a thousand dollars short of that, GDP doesn't increase by a million; rather by somewhat less (accounting for casino depreciation) than the one thousand that went toward the wages of casino employees and the profits to the casino owner and creditors. The approximately $999,000 difference was but a whirlpool outside the circular flow of money, a sort of sideshow the gambler paid to watch, with the services of casino employees.

Likewise, the trophic theory of money says nothing about purely financial (or gambling) activity; only the real labours of those hosting and administering such activity. Therefore flow variables such as "volume of transactions" are not particularly relevant for assessing the trophic theory, because many transactions occur in purely speculative settings. These transactions divert money from the circular flow, similar to play diverting an animal's energy from feeding or reproduction. The trophic theory of money is focused on the origins and quantities of real money supplies and productive flows accounted for in GDP, as reflected for example in the activities listed in the North America Industry Classification System (Office of Management and Budget 2017).

Meanwhile, in managing the money supply, the Federal Reserve System (and analogous monetary authorities in other countries) is focused primarily on staving off high rates of inflation (Axilrod 2013). Although the Fed is hardly known for an ecological background, economists at the Fed (as well as accountants in the Bureau of Economic Analysis) have developed a feel for keeping the money supply in balance with the real sector and its trophic structure. For the money supply to accurately reflect the production and consumption of goods and services in the aggregate is the essence of the phrase "real GDP."

The trophic theory of money under scenarios of recession and collapse

As a basic rule of ecology, any species that uses continuously more energy and resources — as *Homo sapiens* does in the process of economic growth — will reach or breach its carrying capacity. Pursuant to the trophic theory of money, the distinction between reaching and breaching capacity (which may be referred to synonymously as ecological or economic capacity) can be assessed with GDP. Reaching capacity will amount to a stabilization of GDP, or a steady state economy. Breaching capacity will result in declining GDP; i.e., recession or degrowth. If the recession is abrupt and substantial, the scenario may warrant the label "collapse."

Therefore, when economic growth is continuously prioritised, there comes a time when real GDP declines while the environmental impact of economic activity continues to grow. Environmental impact continues to grow due to ecological momentum (such as ecosystem unravelling as a function of climate change), anachronistic efforts to stimulate the economy (such as loosening environmental protections), and the getting by of millions or billions of people, many of whom are now (by definition of collapse) attempting to grow their own food on a crowded and exhausted landscape. This by no means refutes the trophic theory of money. Rather, the dissipation of GDP under these circumstances is analogous to a chemical reaction culminating at a titre level. Instead of being refuted by collapse, the trophic theory of money provides insight to foresee (and potentially obviate) collapse. For example, when a nation's fiscal, monetary, environmental and social policies are designed increasingly for GDP growth, without the desired effects, leaders should recognise that real fundamentals are no longer conducive to growth. Pursuant to the trophic theory of money, these fundamentals include the agricultural and extractive resources available for further capitalization at the trophic base. Conversely, without the trophic theory of money, it is easy to envision policy makers pursuing wispy notions of "dematerialised" GDP.

Variables affecting the relationships among trophic levels, GDP, and environmental impact

The trophic theory of money does not imply that nothing except agricultural surplus affects GDP and real money supplies. We have already noted inflation and accounted for it with phrases such as "real money" and "real GDP." Two other variables are worth mentioning: technological progress and the propensity to use money as a means of exchange.

The effects of technological progress on GDP and real money supplies are relatively straightforward, even if not widely understood. Technological progress is not manna from heaven. Rather, it occurs as a function of research and development (R&D), which in turn is a function of economic growth based upon pre-existing technology (Czech 2008). This latter aspect is overlooked in Pollyannaish visions of dematerialisation. With a firm grasp of the relationships among economic growth, R&D, and technological progress, there is nothing surprising about the declining rates of total factor productivity that seem to perplex many economists and economic journalists (see for example *Economist* 2017). The natural resources available at the trophic base have been heavily harvested over millennia, and many natural capital stocks have been liquidated. The low-hanging thermodynamic fruits (e.g., concentrated minerals lying close to the ground, abundant fisheries, oilfields with high energy return on investment) have been picked. Meanwhile new technologies do nothing to change the trophic demands of the economy. Water, for example, cannot be substituted for. The trophic structure of the economy is fully fleshed out as congruent with Daly's concept of a "full-world economy" (2007:76). R&D is inching to the limits of its capacity to produce new technologies that increase productivity, not for any lack of human imagination, but rather for lack of the real resources required for economic growth. Therefore, technological progress is having less of an effect on GDP and real money supplies than it did in the 20th century. As total factor productivity reaches its limits, so too will the effects of R&D on GDP and real money supplies.

The propensity to use money as a means of exchange self-evidently affects real money supplies. In-home provision of services or widespread reversion to bartering, for example, would lessen the demand for and necessity of money. Nothing about the effect of this variable affects the trophic theory of money or the validity of its corollaries.

Linguistic and rhetorical considerations

The phrase "trophic theory of money" offers substantial linguistic advantages. First, it is clear and concise. It is as it sounds; i.e., a theory of money based upon the trophic principles of ecology. The emphasis on trophic principles is warranted as described in the preceding sections for, without trophic maturation, money does not originate. Although the word "trophic" is somewhat academic, the clarity, concision, and appropriate emphasis of "trophic theory of money" is superior to "money as a function of agricultural surplus" or other less efficient phrases.

"Trophic theory of money" also offers the rhetorical advantage of communicating, emphasising, or reminding readers and audiences of the ecological basis of the economy. As such, it offers the field of sustainability science its own theory of money; a theory most congruent with an emphasis on the

laws of thermodynamics and principles of ecology. It serves to belie the unsubstantiated proposition that real GDP may somehow be de-linked from environmental impact.

Conclusion: the generation of money

Nothing, perhaps, should grate the senses of the sustainability scholar more than the loosely issued phrase "X generated millions of dollars of income," where X might be golfing, shooting, or even gambling. The only activity that clearly qualifies for the title of "generating" money is agriculture. It is agricultural surplus that frees the hands for the division of labour, even unto the entertainments of golfing, shooting, and gambling. Money is spent on these latter activities, not "generated" therefrom.

Not even construction, auto making, or steel refining has a legitimate claim on "generating money." The only activities that might qualify for consideration, other than agriculture, would be those analogous activities that may produce a predictable, widespread surplus of food under conducive ecological conditions. These activities are primarily commercial fishing and domestic livestock production.

With the trophic theory of money we can readily recognise that real GDP and money supplies indicate the amount of agricultural surplus, and in turn environmental impact. Lots of agricultural surplus generates lots of real money; no surplus generates no real money. Limits to agricultural production, therefore, mean limits to real money and real GDP. Long before such limits may be reached, major environmental impacts occur and accrue.

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