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Towards economic geographies beyond the Nature-Society divide

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Abstract

This article suggests an approach to economic-geographic quantification that is relevant to engaging the socionatural blurring of an Anthropocene. It develops representations of commodities and of economies that draw upon concepts of absolute, relative, and relational space to help move beyond legacies of the Nature-Society divide in economic-geographic thought. To supplement familiar ways of knowing commodities as bounded objects with associated single values (prices), the piece rereads input-output approaches, providing accounts of how commodities enfold relations among socionatural phenomena. It quantifies and maps the activities and flows of the global economy in 2007 in terms of their embodied carbon emissions, labor times, and harvested land areas alongside their monetary values. Comparing the perspectives that result, it identifies empirical and theoretical challenges that a political-industrial ecology could help address.

Keywords

Political-Industrial Ecology; Economic Geography; Nature-Society Relations; Relational Space

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1. Introduction

To call for a political-industrial ecology is to invite conversations between two diverse fields, industrial and political ecology (Newell and Cousins, 2014). A political-industrial ecology offers new means through which materiality, meaning-making, and power can be acknowledged in our understandings of contemporary ecologies. What might a political-industrial ecology contribute to spatial and synthetic understandings of material phenomena? This article advocates that one possibility would be for a political-industrial ecology to develop quantitative representations of commodities and of economies that draw upon geographic concepts of absolute, relative, and relational space, helping move beyond legacies of the Nature-Society divide in economic-geographic thought.

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But what sorts of new quantitative knowledges about commodities and economies might we even imagine, much less wish to pursue? Not without reason, prices and money currently play important roles in the ways we narrate phenomena and order our worlds. Invoking GDP lets us know the relative ‘sizes’ of territorial economies. In the process, many economies of the global South come to be viewed to be ‘small’, with many of the North becoming ‘large’, especially when expressed in per capita terms. For those inside, or concerned with, a capitalist firm, it makes eminent good sense to pay attention to quantities measured in price terms, for the health of the balance sheet and the survival of the firm depend on them.

Certainly, geographic critiques of economism are not lacking, as I engage below. Many constructive more-than-quantitative narratives have been offered as supplements and alternatives. With respect to unpacking commodities in particular, multi-sited commodity ethnographic approaches have traced out socionatural entanglements to commodities far beyond what could be known through commodity prices or even through traditional conceptions of economic relations.

Efforts to foster a suitably expansive notion of the common good might nonetheless benefit from broadening what we expect out of economic geographic quantification as well. We should choose a strategy that is complementary to aforementioned more-than-quantitative approaches to knowing commodities (and economies and ecologies, more generally). As industrial ecologists among many others are aware, we do now also know commodities quantitatively through life-cycle analysis and ecological footprinting. Still, even for geographers, it is rare that such measures are positioned or allowed to fundamentally transform the central discourses of economic representation, which still rely on numbers expressed in price terms and are intensive properties located within an absolute space.

Here, I offer interwoven theoretical and empirical contributions. Theoretically, the piece attempts to establish a general approach to quantitatively representing economic phenomena in terms of how their coming into existence embodies and enfolds multiple (types of) events in a myriad of interconnected places. It does so by bringing a geographical attention to absolute, relative, and relational space into conversation with the mathematical methods of interregional input-output analysis. Between the messy networks of socionatural encounters that led to a particular commodity or economic formation and the single numbers that offer simplifications of such networks (e.g., ecological footprint or price), there lie opportunities for theoretical and empirical contributions by relational mathematical approaches. In an era more often focused on finding the right single number or composite index by which to know phenomena through association (e.g., placing prices on natures), I suggest a plural approach to knowing commodities and economies through multiple quantifications associated with multiple conceptions of space.

The other contribution is anchored in empirical results. To illustrate and guide the theoretical contributions mentioned above, I calculate and map several alternative quantifications for global economic phenomena in recent times. Focusing on geographical imaginaries of international trade as a starting point, I offer comparisons between the global economic geographies evoked when we accept an intensive measure such as price for commodity flows versus when we use relational quantitative methods to find how those commodities

embody carbon, land area harvested, or labor time. The economic geographies of global trade from these different perspectives have received varying degrees of attention independently, from considerable (in the case of carbon emissions) to very little (in the case of labor time), but I argue it is important to study more than one of these perspectives at the same time. The results of the calculations presented here are not limited to the example application to international trade, being vastly more intricate than can be exhausted by the summary measures and maps I have space to offer. Many research approaches at various scales that would have known economic phenomena through terms of price could be adapted to study the economy as a more-than-price phenomenon.

The article therefore offers a point of departure, not only for the comparative reconsideration of past research (in economic geography and related fields) that was conducted using terms of monetary price. It also offers entry into a set of parallel or even hybrid realms of future inquiry, in which the quantitative elements of economic-geographic scholarship are not only attentive to the terms and dynamics of the capitalist space economy, but can better contextualize those terms within more-than-human dynamics of the Anthropocene.

2. Economic-geographic quantification and its discontents

Critiques of economic quantification within geography and related fields are longstanding, substantial, and diverse. Economic quantification has tended to center around knowing an economy through collecting, transforming, aggregating, and analyzing the types of numbers that market exchange readily provides. Challenges to such practices are varied, including those that are epistemological, ontological, political, social, ecological and/or institutional in nature. Some argue that economic quantification should be extended beyond the realms to which it is presently applied, others argue that it should be supplemented, and still others critique it for its close connections to the reproduction of (undesirable) contemporary economic relations. Given many such possible directions, I must focus below on engaging those that are most relevant to the project I propose.

Market exchange values elide those phenomena that are not a part of the market, such as subsistence production and also, often, the work of care. In response, is housework to be waged (Federici, 2012)? Is it to be narrated, even valorized, through other approaches (Pavlovskaya, 2004)? What about more-than-capitalist economic relations (Gibson-Graham, 2006)? What about the manners in which the more-than-human world is produced as resources and is (or is not) priced (Lane, 2014)? Monetary prices, if not based on exchange values that have been validated in the market historically, may be estimated through contemporary market transactions of qualitatively similar products. Given that equivalence is complex, especially in the realm of imperfectly equivalent commodities such as land or many contemporary financial assets, modeled prices have increasing social acceptance as well (Bridge, 2011; Williams, 2009). Individuals associated with environmental economics or life-cycle analysis may be more inclined to support various forms of green or 'full-cost' accounting (see Pincetl, 2012). Some researchers argue that capitalism not only does not pay its own way, but that it cannot do so and survive as such (Moore, 2015). Debates around economic quantification thus reach into the heart of capitalist and anti-capitalist politics, unmasking the ideological commonsense of our era by exploring its contradictions.

Quantitative supplements and alternatives to price, or exchange value, have a long history in economic thought and have flourished in recent times. The classical political economists and their critics, especially Ricardo and Marx, debated the relevance of the amount of labor necessary in the production of a commodity to its exchange value (Farjoun and Machover, 1983; Sheppard and Barnes, 1990). Geographers have examined both empirically and theoretically how international trade results in the unequal exchange of socially necessary labor time (Barnes, 1985; Webber and Foot, 1984). Such results have often been offered in the context of debates within political economy, but they are equally of importance to broader understandings of the spatial relations of global economic geography outside of any particular interest in how they relate to price: under globalization, who works for whom, where, and how? At the intersection of economic geography and ecological economics, scholars have also long pursued a parallel set of inquiries into the energy embodiments of economic activities and flows (Hall and Klitgaard, 2012; Lonergan, 1988). Although with important nuances differentiating them, researchers have also constituted concepts around, and examined empirically, how a number of other phenomena are embodied in economic activity and exchange: ‘virtual water’ flows (Allan, 2003), ecological footprints (Wackernagel and Rees, 1998), carbon embodiments (Bergmann, 2013; Davis and Caldeira, 2010), human appropriations of net primary productivity (Erb et al., 2009), and land use (Bergmann and Holmberg, 2016; Henders and Ostwald, 2014). Such alternative economic calculuses can be used to supplement price. But they can also be used by those who aspire to perfect the price mechanisms of markets., as in environmental pricing reforms such as carbon taxes.

In this piece, I explore a different interpretation of such quantifications and their ends. Let us consider what happens if these other quantities *are* dimensions of the economy, considered in some sense co-equal to quantifications of exchange value. Instead of treating such numbers as the associated distal environmental (and social) impacts associated with particular commodities—commodities understood first and foremost within an economic discourse that centers prices and the market—we expand the notion of ‘economy’ in economic quantification. Here, numbers such as carbon and labor embodiments are not merely seen as separate alternatives to a monetary price each studied in their own scholarly discourses addressing and all reinforcing notion of ‘the economic’ rooted on the social side of a Nature/Society divide. Below, all such socionatural perspectives on economic phenomena are instead simultaneously positioned to be understood as interrelated until demonstrated otherwise.

There are several forms of ontological reductionism at the heart of economic quantification. There is the matter of associating a *number* with an object. Many critiques of such quantification regard the logic of counting as central. Quantification often must render equivalent substantial swaths of the world’s diversity in order to create a ‘1’ that can be added to another ‘1’ (Doel, 2001; Nietzsche, 1979). The idea that an object is knowable as a ‘1’ similar to other ‘1’s maps entities to the realm of whole numbers. Economic quantification relies upon such whole numbers in the counting of businesses or workers. Measurements of price, weight, and volume partake of a slightly broader calculative logic of real numbers, even if such acts of quantification still typically correspond one phenomenon with one number at a time. Associating prices with objects enables capitalist calculation and

renders the process of valorization at the heart of circuits of capital pursuable. Such reductionism may ultimately be a price that must be paid when using numbers. It is important to understand such limits alongside the limits to language generally (Olsson, 1991).

Still, here, instead of seeing economic quantification as being a matter of having a single real scalar (price) mapped to a phenomenon, the quantifications offer economic-geographic representation the use of a set of numbers, or a vector, to be associated with a phenomenon. I thus propose a socionatural broadening of the recent calls for using ‘families’ of footprints (e.g. Fang et al., 2014; Galli et al., 2012) that bundle multiple metrics in environmental management and avoidance of planetary boundaries. This approach does mitigate the ontological reductionism discussed above somewhat. Quantifying via several numbers within vectors instead of via single scalars increases the number of axes on which different entities can differ quantitatively. It also renders quantitative comparison more ambiguous, as more than one metric exists to compare vectors.

Whether or not we associate multiple numbers with a single bounded phenomenon, there are also costs and benefits to considering phenomena as always-already individuated, ontologically self-sufficient entities. This is another form of reductionism: associating a number with an *object*. Here, I refer to a certain commonplace notion of object, that associated with Cartesian reductionism and absolute space, as we discuss below (not the object as transformed by speculative realism and object-oriented ontologies, e.g., Bryant, 2011, which bring objects into debates around process-relational ontologies more characteristic of the alternatives I provide here; Ivakhiv, 2014). When economic phenomena such as commodities are fetishized, individuated, and essentialized, economic knowledge of commodities and economies no longer requires or provides understanding of their [more-than-]human socionatural relations.

Critiques of commodity fetishism are common in contemporary geographic research. Counter-practices ‘follow’ the more-than-human webs of the commodity through multi-sited ethnography (e.g. Cook, 2004). Deeper social histories of seemingly natural commodities can be traced (Head et al., 2012). Commodities are also often framed within inclusive Global Production Network (GPN) approaches examining diverse actors, power, discourse, and materiality (Coe et al., 2008; Gibson and Warren, 2016). But how can quantitative economic geographies converse with and complement such accounts, accounts that tend to rely upon relational notions of space and economy?

3. Other economic-geographic quantifications for other spatialities

In thinking through different ways to understand phenomena quantitatively in terms beyond those of price alone, Harvey’s (2006) conceptual differentiation between absolute, relative, and relational space can be useful. This article engages Harvey’s formulations not out of the sense that this is the only way to proceed. There are many notions of relationality—such as those emerging out of the feminist, poststructural, and new materialist literatures—that offer different but related points of departure (e.g., Bergmann, 2016). For the purposes of the argument here, it is particularly productive to engage Harvey’s articulations of absolute,

relational, and relative space given the context of his historically influential and complex relationship to mathematical methods.

Figure 1 provides examples that help illustrate and differentiate Harvey's approaches to these three concepts of space. If it seems a bit irrelevant to speak of space in a piece dedicated to discussing alternative ways of quantifying phenomena (which merely exist within space), then the notion of space one has in mind is likely that which Harvey, among other geographers, terms absolute space; whereas the ontology of phenomena that is assumed is largely one of always-already individuated entities, an ontology of Cartesian reductionism (Harvey, 1996; Levins and Lewontin, 1985). Indeed, absolute space, Harvey writes, "becomes a 'thing in itself' with an existence independent of matter. It then possesses a structure which we can use to pigeon-hole or individuate phenomena" (1973, p. 13). Entities, here, have intensive properties and their interrelations are 'external'. Or, in our terms here, commodities are things with property of price, prices whose socionatural relations are masked by commodity fetishism.

There are other concepts of space and objects, views in which the two are inseparable, dynamically co-produced. Harvey continues, "The view of relative space proposes that it be understood as a relationship between objects which exists only because objects exist and relate to each other" (1973, p. 13). Relative space does not provide the external metric of absolute space that is typical of today's geographic information systems, with the space instead emerging from the relations between objects. As was noted by a key text of an earlier, perhaps surprisingly experimental, moment within quantitative geography, "The shift to a relative spatial context is still in progress, and is probably the most fundamental change in the history of geography as it opens an almost infinite number of new worlds to explore and map..." (Abler et al., 1971, pp. 72–73). Einsteinian space-time was an inspiration for its challenge to Newtonian space more than for any relevance it had to the physics of everyday life. Today, the emergent quality of time and length scales found within dynamical systems approaches might also be of note. But what about the ontological status of objects themselves? It is less clear; perhaps they are again largely the individuated entities of Cartesian reductionist ontology.

But, "there is another sense in which space can be viewed as relative and I choose to call this relational space – space regarded in the manner of Leibniz, as being contained in objects in the sense that an object can be said to exist only insofar as it contains and represents within itself relationships to other objects" (1973, p. 13). Leibniz was the most prominent figure in European philosophy offering a contemporary alternative to Newton's approach to space and, relatedly, an advocate for a monadic ontological tradition to which Deleuze (1993), Tarde (2012), Latour et al. (2012), and Law (2004), among others, have variously contributed. In *Justice, Geography, and the Nature of Difference* (1996), Harvey places Marx, Whitehead and Leibniz in conversation and develops, at length, an approach to the type of relational space he has revisited repeatedly throughout his writings. Such a relational approach intertwines space and phenomena, yielding internal not external relations: "external influences get internalized in specific processes or things through time.... A wide variety of disparate influences swirling over space in the past, present and future concentrate and congeal at a certain point...to define the nature of that point" (Harvey, 2006, p. 124).

Harvey, in Figure 1, notes rental and economic potential surfaces as entities characterized by a relational approach to space, having already argued back in 1973 that, “Parcels of land also capture benefits because they contain relationships with other parcels ... in the form of rent relational space comes into its own as an important aspect of human social practice.” (1973, p. 13, as excerpted by Harvey 2006). If so, what potentials may we find in an ecological footprint or a life-cycle analysis? Like economic potential surfaces, these metrics are not directly observed, but may be understood through conceptualizations of space that rely on relational enfoldings; they use the empirical though they are not crudely empiricist. Below, we explore how variants on input-output data and analysis might offer a quantitative approach to tracing out such enfoldings.

Yet Harvey has long been wary of the possibilities for quantitative approaches to many sociospatial phenomena. This has been of some historical significance to geography and those interested in relational approaches to space. In 2006, Harvey wrote, “Measurement becomes more and more problematic the closer we move towards a world of relational space-time.... This leads to some interesting reflections on the failure (perhaps better construed as limitations) of positivism and empiricism to evolve adequate understandings of spatio-temporal concepts beyond those that can be measured. In a way, relational conceptions of space-time bring us to the point where mathematics, poetry, and music converge if not merge. And that, from a scientific (as opposed to aesthetic) viewpoint, is anathema to those of a positivist or crudely materialist bent.” (124).

The nuances of this framing are considerable, especially given that some of the entries within Figure 1 are concepts whose expression is often mathematical. Does a quantitative approach require positivism, or a positivist commitment require quantitative methods? If we agree with those who have argued and demonstrated that the answer can be no (see Barnes, 2009; Poon, 2005; Sheppard, 2014), then what other roles might ‘measurement’ play? If ‘measurement’ itself is too literal, too tied up with specifying intensive properties to phenomena within absolute space, to be a part of a relational spatiality, could there be mathematical means by which such entities of absolute space can be reread within relational frames? While acknowledging the difficulties involved and the necessarily exploratory nature of the inquiry, this article suggests benefits to pursuing a poetics of space that embraces the mathematical alongside the relational.

4. Quantitative economic geographies for the Anthropocene: absolute, relative, and relational

Is one of these approaches to understanding space the *correct* approach? Harvey, at least, has long argued there is no abstract answer to such questions, instead suggesting we ask: “how is it that different human practices create and make use of different conceptualizations of space?” (1973, p. 13). Below, I invite us to consider how relational mathematical methods can lead us to rethink how we represent global economic geographies within absolute, relative, *and* relational spaces. In doing so, I calculate how the global economy would appear if it were understood not primarily in terms of monetary values, but equally quantified and mapped according to embodiments of labor time, carbon emissions, and land area harvested.

I consider the ‘intensive economic geographies’ of absolute spaces first, by recasting economic quantifications of global commodities from their prices to how they differ in their embodiments of various socionatural phenomena. Although the mathematical methods used invoke a relational approach to space and phenomena, the results obtained are largely interpretable within absolute spaces. In the next subsection, I employ relational methods to redenominate economic-geographic flows in a relative space, inviting us to rethink our geographical imaginaries of global trade. Finally, I explore possibilities for engaging more directly with the global economy reframed in terms of relational space, where many tantalizing challenges for developing mathematical and visual practices remain.

The departures I offer employ variations on the mathematics of environmentally-extended input-output analysis, as seen below. All my analyses here rely on the Global Trade Analysis Project (GTAP) data base, version 8.1 (Narayanan et al., 2012). The GTAP data base is commonly used for global-scope interregional input-output analyses, with results that are relatively comparable to those obtained from calculations with alternative datasets (Inomata and Owen, 2014). Crucial for the purposes of this article, these are databases with appropriate satellite accounts for carbon emissions (Bergmann, 2013; Narayanan et al., 2012), land use (Baldos and Hertel, 2012; Bergmann and Holmberg, 2016), and labor (via the GMig2 migration data base; Walmsley et al., 2013; Bergmann and Sheppard, in preparation). All data are about 2007, a high water mark of Euro-American-centered globalization.

The core data base of GTAP 8.1 subdivides the world into 134 regions, providing extensive statistics on economic interactions within and across regions. There are 57 intermediate economic activities, with associated domestic exchange, production techniques, and international trade flows. The data base also provides a number of additional accounts associated with final demand, factor inputs, and regional households. I prepared a variation on a Social Accounting Matrix (SAM) according to the methods developed by Bergmann (2013), which combine and updates approaches to developing social accounting matrices from GTAP data (McDonald and Thierfelder, 2004) with the calculation of interregional flows originally introduced by Rodrigues et al. (2011). The dimensions of the resulting SAM, $\mathbf{S}$, are 11394×11394 , with up to 130 million interactions between the different places, peoples, and economic activities of the world. Each entry in the SAM, S_{mn}^{ij} , is the amount of product m in region i required as direct input to produce the overall production of product n in region j in a particular year. The notion of ‘product’ here is very general, with sugar, vehicles, insurance, and labor power, among others, all being products.

4.1 Intensive economic geographies

4.1.1 The commodity as multiple—Following Bergmann (2013) and input-output analysis generally (Miller and Blair, 2009), I calculated the open Leontief inverse, ${}_q\mathbf{L}$, whose entries ${}_qL_{mn}^{ij}$ estimate the direct and indirect amounts of the phenomenon q (e.g. carbon, land, labor) embodied from product m in region i required to produce a unit of n in region j :

$${}_q\mathbf{L} = \widehat{\mathbf{f}}[\mathbf{I} - \mathbf{A}]^{-1} \quad (1)$$

This expression makes references to several types of information. First, $\mathbf{A}$ is an interregional input-output table, a matrix whose entries A_{mn}^{ij} are the amounts of product m in region i required as direct inputs to produce a unit of n in region j . In GTAP, three of these products are different modes of transportation used to render other products in one region accessible in another region. $\mathbf{A}$ is a submatrix drawn from $\mathbf{S}$. Which columns and rows of $\mathbf{S}$ are excerpted to form $\mathbf{A}$ is decision with entwined intellectual, numerical, and political stakes (Bergmann, 2013; Bergmann and Holmberg, 2016). In deciding how $\mathbf{A}$ will be extracted from $\mathbf{S}$ and thus in implicitly defining the scope of the exogenous demand vectors y (where y_n^{ij} are monetary amounts of commodity n directly purchased from region i to satisfy demand in region j), a tradeoff is made between the breadth of purposes for which embodiments can be used and the comprehensiveness with which commodity chains are traced. I below use the more focused and complete version of consumption-based modeling offered by recent research (the “C_C model” from Bergmann, 2013), aware that all such single modeling perspectives both render visible and obscure. The degree to which different such perspectives yield different resulting perspectives is a question to which a political-industrial ecology might attend, though it is not the project of this present piece.

Second, ${}_q\mathbf{f}$ is a vector whose entries are the amounts of a given type of phenomenon (e.g. labor time, carbon emissions, land area harvested) denoted by q directly required by, associated with, emitted by, etc., various products, m ; ${}_q\widehat{\mathbf{f}}$ is a diagonal matrix whose entries are ${}_q\mathbf{f}$. Finally, regions i taken together form a set below termed R ; all sectors m together are the set S ; and $\mathbf{I}$ is an identity matrix.

The total amount of q embodied in a dollar of product n produced in region j , ${}_qT_n^j$, is then:

$${}_qT_n^j = \sum_{i \in R, m \in S} {}_qL_{mn}^{ij} \quad (2a)$$

These are the embodied intensities (below, labor, carbon, and land intensities) of a commodity n produced in region j . The ${}_qT_n^j$ carry the units of a given q per dollar (or other currency). If a commodity costs d dollars, then the embodied cost (in terms of carbon, land, or labor, among other possibilities) needed up the commodity chain to realize that commodity is $(d) \left({}_qT_n^j \right)$. Various such forms of ${}_qT$ can be calculated for different levels of aggregation and breadths of averaging across classifications of commodities.

All ${}_qT$ provide optics needed to reframe the vision of the economy beyond the singular world of monetary units. They offer conversion factors between existing quantifications of economic phenomena (such as commodities or territorial economic outputs) expressed in units of dollars and the expression of those economic phenomena in units of embodied kilograms, hours, square kilometers, or other metrics. Global economic phenomena can thus be compared and contrasted across different standpoints, providing a path to bring the social, ecological and economic into the same plane. A given phenomenon, such as a commodity, a trade flow, or the economic output of a territory, can be understood in terms of any single one of these quantitative perspectives, as a scalar, or in terms of a plurality of perspectives

simultaneously, as a vector of $(d) \begin{pmatrix} pT_n^j \end{pmatrix}$ for a number of different q . Most generally, the representation of all flows in the global economy offered by $\mathbf{S}$ can be pluralized and made perspectival as well, with a different ${}_q\mathbf{S}$ offering a different view of world economic activities and flows in terms of each socionatural phenomenon q .

Industrial ecology (and life cycle analysis, in particular) has given us quantitative insights into the material requirements and implications for pollution of producing particular commodities through given commodity chains and networks. Commodity ethnographies provide complementary socionatural analysis. Such work suggests that commodities viewed similarly from lenses of use value and price can differ widely around the world in how they embody labor, land, and carbon. Figure 2 uses the approach offered above (comparing various various ${}_qT_n^j$) to examine how different commodities around the world embody different relations between labor, carbon, and land intensities. The calculations are done using Equation 2a at the maximum level of disaggregation for GTAP 8.1 data, but then ranges of sectors within each of the 134 regions are aggregated into three abstract commodities for display: [A]griculture (GTAP sectors 1-13), [M]anufacturing (sectors 14-46, including processed primary goods), and [S]ervices (sectors 47 and above). Each scatterplot in Figure 2 plots these (134×3) 402 commodities at the point given by that commodity's total embodiments of two of these different phenomena (land, carbon, and labor) and/or the GDP per capita of the region.

A number of patterns in Figure 2 deserve further investigation, not only through inferential statistics, but also in terms of what they suggest may be relevant theoretical conversations for economic geography to pursue with a political-industrial ecology. One line of inquiry is hinted at by the plots involving GDP per capita. GDP per capita for a given region provides one way to narrate territorial positionality within the uneven development of the capitalist space economy. The relationships in Figure 2 between regional GDP per capita and the intensity measures can be quite nonlinear. There are trends toward the commodities from regions with higher GDP per capita having lower per-dollar intensities of labor and land (and less obviously so with respect to carbon). None of these perspectives visibly suggest a substantial environmental Kuznets curve (Fischer-Kowalski and Amann, 2001; Roy Chowdhury and Moran, 2012), in which intensities would form an inverted 'U' with respect to GDP per capita, with low and high income per capita having lower intensities than regions at intermediate levels of income per capita—though carbon embodiment may be a candidate with closer inspection. Across all regions, services tended to have lower intensities of not only land and carbon, but also labor time, per dollar. Agriculture had the highest embodiments of labor time and land use, but middling intensities of carbon. These patterns are reflected in relatively distinct clusterings in the land-carbon intensity space of the plot, seen at the lower right of Figure 2. There are few products that are low labor intensity and high carbon intensity. The combination of such systematic patterns coupled with strong contextual variability in the socioenvironmental dimensions to production all visible in Figure 2 suggests multiple dimensions of a political-industrial ecology (from attention to geographical political economy to the more focused empirical practices of life cycle analyses and commodity ethnographies) are important to the constitution of an economic geography adequate to the Anthropocene.

It is important to note that some of the variation here is due to how the bundles of products that constitute a category such as “Agriculture” or even its component sectors vary in composition across regions. Production techniques and sourcing of inputs inevitably vary even within a sector, but input-output data and analysis tend to only approximate such diversity in distributions by measuring and calculating using arithmetic means, which can lead to misleading results (Farjoun and Machover, 1983). The fact that this is also true for the products of even relatively narrowly defined industries suggests important roles for the specificity and nuance achievable through individual commodity studies.

Still, there is room for more nuance using computational methods, and not only by relying on finding data that is more disaggregated. Thus far, we have been discussing the embodiments to commodities produced in a region. Yet the commodities produced within a region are rarely entirely equal to those consumed in a region. Data of the sort used above thus allows for the differentiation between the average product n produced in a region versus the average product n consumed in that region. The amount of q embodied in a dollar of the average product n consumed in region j is thus given by ${}^cT_n^j$:

$${}^cT_n^j = \frac{\sum_{i \in R} \left({}^pT_n^j + {}_q\delta_n^{ij} \right) y_n^{ij}}{\sum_{i \in R} y_n^{ij}} \quad (2b)$$

In the above, y_n^{ij} are amounts of commodity n (measured in money) directly purchased from region i to satisfy demand in region j . Further, ${}_q\delta_n^{ij}$ are the amounts of q that were associated with the use of the transportation commodity in the process of rendering one unit of commodity n in region i accessible to region j . Similar information is implicitly used in the construction of the interindustry table within $\mathbf{A}$ and is thus included within ${}_q\mathbf{L}$ and ${}^pT_n^j$, but needs to be again directly included here to account for the additional production of accessibility needed for a given commodity to travel from its point of production to its point of use. Other measures of the contents of a given type of commodity with respect to a given substance or phenomenon are also possible; their feasibilities will vary given the type of input-output data used.

Ultimately, the particular standpoint taken and question posed renders single commodities or economic aggregates comparable in different ways, perhaps even reordering how ‘large’ they are with respect to one another; relative economic magnitudes and economic geographies are thus perspectival, even considered quantitatively.

4.1.2 The region as multiple—The typical intensities of labor or land or carbon found in a given region’s production or consumption can also be estimated, offering another point where the concerns of geographical political economy enter into conversation with understandings of the Anthropocene. Let the total output of sector n in region j be x_n^j . Averaging over all types of commodities, the amount of q embodied in the average dollar of production, ${}^pT^j$, and consumption, ${}^cT^j$, in region j are then given by:

$${}_qT^j = \frac{\sum_{n \in S} {}_qT_n^j x_n^j}{\sum_{n \in S} x_n^j} \quad (3a)$$

$${}_qT^j = \frac{\sum_{i \in R, n \in S} {}_qT_n^j y_n^{ij}}{\sum_{i \in R, n \in S} y_n^{ij}} \quad (3b)$$

Figure 3 plots the results for different global regions, j , and phenomena of interest, q .

Arrows from production intensities $\left({}_qT^j\right)$ to consumption intensities $\left({}_qT^j\right)$ for different regions are shaded by whether they are net exporters (blue) or importers (red) of the phenomenon in question.

For labor time and area of land harvested, countries with lower income per capita tend to be net exporters to those with higher incomes. The embodied cropland and labor time consumed in countries that have higher GDP per capita depends very considerably on imports. Carbon emissions, however, suggest a different pattern in which the relatively high emitters per capita at a given level of national income per capita are net exporters. The panels on the right show that a few countries have relatively large trade imbalances in both labor and carbon terms, whereas the magnitudes of cropland imbalances for individual countries are relatively less polarized.

4.1.3 Understanding economic geographies through plural intensities—

Conceptually, the ${}_qT$ found in Equations 2–3 form the basis for a multiplicity of scalar economic quantifications that complement the traditional market exchange value denominated in terms of money. Indeed, instead of quantifying a phenomenon economically primarily by using a single real scalar denominated in terms of money, d —given the multiplicity of perspectives on the phenomenon derived above, we can now understand economic phenomenon more generally quantitatively as a vector of real numbers, Ω (conceptually infinite in length, but practically finite). Each element in this vector corresponds to a ${}_qT$ for a different q , and thus for a different dimension through which a phenomenon such as a commodity could be known quantitatively. In this more general way of quantifying an economic phenomenon, the market price, d , is only one among many numbers (one where is simply market price with corresponding ${}_qT$ of 1). Other elements of Ω correspond to quantifications of phenomena in other terms that may be equally important to an economic geography for the Anthropocene, such as net carbon emissions required to realize the product, direct and indirect human labor time, biodiversity encountered, landscape area depended upon. If the challenges of the Anthropocene are to be engaged, all these quantities should be recognized as interrelated quantitative understandings of economy and economic geography.

Ultimately, while such vectors distill relational geographies within themselves, intensive numbers (whether individual scalars or combinations of scalars as vectors) obscure those relational geographies. They offer traces of a commodity's entanglements beyond itself, of the commodity's participation in more-than-monetary entanglements. But they are themselves still abstractions away from the concrete geographical entanglements of the commodity, past, present, and future. Below, we explore possible quantifications associated with relative, and then relational, spaces.

4.2 Relative economic geographies

Many economic flows are bundles of commodities (e.g., the various products that form the exports from China to the United States in a given year). It is common to render the elements of these bundles commensurate in order to aggregate them; we often represent elements by scalar real numbers (prices) and use simple addition to consolidate many numbers to one (in the case of the aforementioned trade flow, the total value of exports from China to the United States in a year). If commodities are now to be known not by single scalars, but by vectors expressing a multiplicity of quantitative perspectives, a similar simplification of a bundle of entities to a single entity via addition is still possible, but the result is likewise a vector.

$${}_qE^{ij} = \sum_{m,n} {}^pT_m^i S_{mn}^{ij} \quad (4)$$

The expression ${}_qE^{ij}$ offers a variety of different valuation perspectives on trade flows, from region i to region j , measured from different perspectives q . Taken individually, these ${}_qE^{ij}$ describe the bilateral flows between two territories in terms of embodiments of labor time, carbon, or land, among others. Such flows may also be contextualized, implicitly or explicitly, within the network of all other flows among places. In this case, a network (graph) is defined by the combination of the set of regions R as the nodes (vertices) with the weights of the links (edges) among them defined by ${}_qE^{ij}$. Different phenomena q define different networks (graphs) among the regions, with each network having its edges measured in a particular type of unit. It then becomes possible to research how the geography of global flows differ when considered in terms of carbon versus of money, for example. Such networks can also be understood as forming as a single multiplex network together—multiple types of edges interconnecting a single set of nodes—or even a single network whose edges are weighted not by scalars but by vectors akin to the Ω mentioned above. At this point, structural analysis (Doreian et al., 2004; Reichardt and White, 2007; Wasserman and Faust, 1994) of how different perspectives of global economy compare and contrast become possible (e.g., the different ‘roles’ played by regions or industries within complex networks.)

Figure 4 is a graphical representation of ${}_qE^{ij}$ for different phenomena q considered in this article. Each panel displays different dimensions of (what ideally are unboundedly) plural vectors Ω , whose analysis in relation by means offered above suggests a more synthetic

approach to economic geography for an Anthropocene. In the present form, Figure 4 indicates that, in monetary terms, much of global trade happens between countries of the mid-latitudes in the North. In comparison to other manners of quantifying these flows, the monetary perspective is comparatively balanced. When trade is understood instead in terms of embodied land harvested, many of the flows from the global South to the North become quantitatively larger and more comparable to those among the North. Quantifying global trade in terms of embodied carbon emissions reveals exports from China to be quite dominant, dwarfing most other trade flows among other places. A similar, or even more polarized, pattern with Chinese exports at the center of world trade is seen when flows are quantified in terms of the labor time they took to produce, though exports from India and Africa are not entirely insignificant in such a calculus. Intra-core flows, such as those of the Euro-American trade, may be dominant measured in terms of money; but they pale in global significance when understood in terms of the labor time, carbon, or land they took to produce.

4.3 Computational Engagements with Relational Space in Economic Geography

The *intensive* and *relative* geographies of trade examined in the preceding sections have resulted from the use of *relational* quantitative methods. Properly contextualized, the reader can understand such representations of a commodity or region as embodying enfolded connections to, and contributions from, many distant processes and places. But more explicitly relational geographical representations of a commodity might not aggregate process-relational webs into single numbers or flows. At least in many commodity ethnographies and related approaches, relational approaches can be direct in how they portray complex crossings of conceptual and territorial borders. They sketch the global relations seen when peering ‘down’ into the baroque complexities of a monad (Law, 2004). Process-relational webs are themselves important results and objects of inquiry. Can the relational computational methods advocated above offer comparably rich relational geographical depictions?

Indeed, the calculations above in Equation 1 implicitly required the tracing of many intricate and infinite webs enfolded into particular commodities, places, and peoples. It was in the context of the analyses and visualizations I chose as examples in the sections above that I aggregated such webs into finite and narrow sets of numbers and linkages. However, one could focus on a single commodity, a place, or a group of people, then trace interconnections outwards. For a unit of a given product n in region j , there are up to approximately $|R| |S|$ potential types of inputs across all products m in regions recorded by non-zero entries, ${}_q S_{mn}^{ij}$, of the social accounting matrix ${}_q S$ (which, as described above, is here no longer denominated in terms of monetary price, but may be expressed in units of other socionatural phenomena, q). If these are the ‘first order’ connections in a web of associations that led up to product n in region j , then the second order connections can be given by applying to same logic to each first order connection, increasing the number of possible connections by a factor of $|R| |S|$. Subsequent stages can follow. Such endlessly forking paths may be placed into graph (network) or even hypergraph structures.

The interpretative processes of ethnography tend to curate which such interconnections matter in the case of qualitative commodity studies. An associated mixed methods approach may be possible within a political-industrial ecology. Those interconnections that are of greatest analytical interest can be traced through fieldwork, with more computational tracings taking over at a greater 'distance' from the central topic of interest in order to provide context difficult to gather via fieldwork. Such computational-ethnographic hybrid practices may find a degree of inspiration in the methods developed for situating life-cycle analyses within environmentally extended input-output models (Hendrickson et al., 2006).

But compared to the representations of intensive and relative geographies above, which can draw upon the visual and computational lexicons of much existing work in cartography and complex networks, there are fewer existing computational inspirations for the analysis and narration of a properly relational geography in its own terms. Tools from input-output analysis, such as structural path analysis (Lenzen, 2007), may be useful for determining which sets of interconnections are, in a sense, numerically exceptional. Interactive visualizations of network diagrams may be of some interest. However, generally, the design of analytical operations and visual practices more fully adequate to a computational treatment of relational geographies is an area for research (Bergmann, 2016). As a political-industrial ecology is committed to both political and industrial ecologies, more such work is needed.

5. Conclusions

Significant challenges (and opportunities) exist in the development of the methods advanced in this article for the purposes of a political-industrial ecology. Most social accounting data will likely remain quite aggregated, spatially and sectorally. Achieving analyses that differentiate among global cities or between city and country will not be easy (though see Bergmann and Holmberg, 2016). But even with the present detail of data sources, the difficulties of conducting, interpreting, and visualizing analyses embracing the uneven interconnection of all things can lend themselves to a tactical embrace of further aggregation and abstraction in both territorial (e.g., continents) and categorical (e.g., 'agriculture') terms, as seen above. An ethnographic approach to studying commodities is better positioned to avoid reconstructing abstractions that characterize received notions of 'the economic'. But there is also deconstructive value to the tactical embrace of such categories by a *relational* quantitative approach: the particular 'presence' and ontological self-sufficiency of any such phenomena and categories are thrown into motion, relation, and question. Just as our qualitative accounts of commodities, peoples, and spaces can be ontologically rich and relational, our quantitative accounts need not act to create bounded entities with intensive properties in an absolute space.

There are silences that originate with existing input-output data, whose building blocks are collected and compiled by individual states as a part of their national economic accounting. Consequently, social accounting data tends to deemphasize those dimensions of social life not well-expressed by market relations. Symbolic practices and power relations are just two of the dimensions to contemporary economic geography that are difficult to bring directly in to input-output data and analyses that follow from them. There will remain relations to

which life-cycle analysis and (especially) ethnographic work have access that the methods of this article will only be able to engage through hybrid and mixed methods. Fostering an engaged pluralism (Barnes and Sheppard, 2010) would be useful to political-industrial ecology.

The approaches that have been developed here do suggest paths that may lead past some lingering legacies of the Nature-Society divide in economic geographic quantification. To help economic geography rise to the intellectual challenges of the Anthropocene, we must remember the important reasons why we have rendered phenomena quantitatively knowable in terms of their prices, but we should also embrace quantitative representations that recognize how those phenomena enfold relations with socionaturally-diverse and seemingly-distant other phenomena. The explorations above demonstrate how different our geographic imaginaries of the global economy can be when built from the various perspectives offered by price, carbon, labor, and land. While patterns and resonances among the resulting global imaginaries suggest a continued role for theory at all scales within political-industrial ecology, substantial variations indicate the necessity of focused case studies that only empirical fieldwork (or hybrids thereof) can provide. The redenominations of global economic geographies here may also lead to new studies seeking to compare the results of economic-geographic analyses performed in monetary terms with those performed in terms of carbon, labor, or land, among others. Finally, just as there can be political stakes and debate within civil society regarding which map projections should or should not be used in the representation of the world, it is conceivable that the multiple re-visionings of global economic geography offered here could be taken up by a variety of actors and interpreted in support of diverse claims. The relationships between the global North and various parts of the global South differ substantially across the panels of Figure 4, for example.

The concept of ‘the economy’ suggested by the representational reconstruction in which this article has engaged may not quite be ‘the economy’ to which many are accustomed. But at the same time, those results offer us a position to speak to substantial issues that geographers, with long traditions of synthesis across social and natural inquiry, have sought to address.

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	Material Space (experienced space)	Representations of Space (conceptualized space)	Spaces of Representation (lived space)
Absolute Space	walls, bridges, doors, stairways, floors, ceilings, streets, buildings, cities, mountains, continents, bodies of water, territorial markers, physical boundaries and barriers, gated communities...	cadastral and administrative maps; Euclidean geometry; landscape description; metaphors of confinement, open space, location, placement and positionality; (command and control relatively easy) – <i>Newton and Descartes</i>	feelings of contentment around the hearth; sense of security or incarceration from enclosure; sense of power from ownership, command and domination over space; fear of others "beyond the pale."
Relative Space (Time)	circulation and flows of energy, water, air, commodities, peoples, information, money, capital; accelerations and diminutions in the friction of distance...	thematic and topological maps (e.g. London tube system); non-Euclidean geometries and topology; perspectival drawings; metaphors of situated knowledges, of motion, mobility, displacement, acceleration, time-space compression and distanciation; (command and control difficult requiring sophisticated techniques) – <i>Einstein and Riemann</i>	anxiety at not getting to class on time; thrill of moving into the unknown; frustration in a traffic jam; tensions or exhilarations of time-space compression, of speed, of motion.
Relational Space (Time)	electromagnetic energy flows and fields; social relations; rental and economic potential surfaces; pollution concentrations; energy potentials; sounds, odors and sensations wafted on the breeze	surrealism; existentialism; psychogeographies; cyberspace, metaphors of internalization of forces and powers; (command and control extremely difficult – chaos theory, dialectics, internal relations, quantum mathematics) – <i>Leibniz, Whitehead, Deleuze, Benjamin</i>	visions, fantasies, desires, frustrations, memories, dreams, phantasms, psychic states (e.g. agoraphobia, vertigo, claustrophobia)

Figure 1.

"A general matrix of spatialities," from Harvey (2006, used with permission), suggests examples and key theorists of different approaches to space and phenomena. The vertical distinguishes absolute, relative, and relational spaces. Space is differentiated in a Lefebvrian manner along the horizontal.

Figure 2.

How the commodities of the world differ in their relative intensities per dollar of embodied carbon, labor, and land (including croplands, pasturelands, and forests), depending on which region (and at what GDP per capita) produces them. Each plot shows the aggregated commodities of [A]griculture, [M]anufacturing, or [S]ervices in each of 134 regions spanning the world. Each graphic thus shows the same 402 commodities (3×134) from a different combination of perspectives.

Figure 3.

Ecological-economic positions of regions under globalization. Regions that are net importers are shown in red, with exporters in blue. All panels have GDP per capita along the abscissa. The three rows of panels, from top to bottom, reflect regional embodiments of labor time, carbon emissions, and cropland area harvested, respectively, measured along the ordinate. The left column of panels have per capita measures along the ordinate; the right, overall regional totals. Individual regions each have one arrow, drawn from the regional production-based measurement toward the regional consumption-based measurement.

Figure 4. Four interpretations of global trade. Arrows flow from exporters to importers; widths represent the relative quantitative values of trade flows, as calculated in the respective units indicated in the figure corners. Color merely differentiates 11 (mostly contiguous) macroregions, territories to and from which all flows have been aggregated for the purposes of visualization. Briesemeister projection.