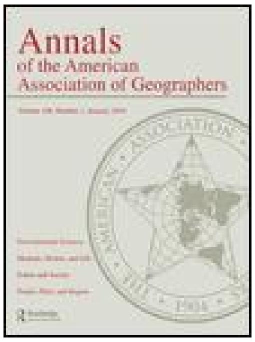

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Land in Motion

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Globalization entwines human lives with distant fields and forests. In response, our approach to land is relational yet also computational. We calculate and map intricate connections among land uses and distant populations mediated by both commodity chains and capital, thereby unpacking, deepening, extending, and pluralizing recent methods estimating land footprints of commodity consumption. After constructing networks of approximately 130 million direct connections among land uses, economic activities, and peoples of the world in 2007, we trace infinities of indirect interconnections. Dominant absolute-space approaches to human–environment relations facilitate local comparisons of population and resources, but our relational quantitative approach provides maps and metrics that illustrate how uneven development under neoliberal globalization results in strong global net redistributions of various per capita benefits from land use, especially from Global South to Global North. From the perspective of capital investment, the median square meter of global land use contributes to futures of human populations outside, not inside, of the country of that land. Many connections to land reach us in the form of manufactured goods and services, not just through food and fibers. Our conclusions require simultaneous examination of the indirect interconnections of all commodities, activities, and places; our characterizations of land and globalization thus differ from the forms of evidence used in studies examining single commodity chains or offered by direct trade statistics, although the results are often complementary. We show that geographical political economy and relational quantitative approaches to space have much to offer understandings of land in the Anthropocene. *Key Words: capital, consumption, globalization, land use, relational space.*

全球化让人类与距离遥远的土地和森林紧密结合。为了回应此一议题, 我们探讨土地的方式是关係性的, 但同时也是计算的。我们计算并绘製透过商品链与资本中介的土地使用与远距人口之间错综复杂的连结, 以此揭露、深化、延展并多元化晚近评估商品消费的土地足迹之方法。我们建构 2007 年的土地使用、经济活动与世上人类之间约一亿三千万的直接连结网络之后, 追溯间接互动的无限性。探讨人类—环境关係的主流绝对空间方法, 促进了人口与资源的在地比较, 但我们的关係性量化方法, 则提供了地图与计量指标, 描绘新自由主义全球化下的不均发展, 如何导致来自土地使用的各种人均获益的广大全球淨值再分配, 特别是从全球南方到全球北方。从资本投资的视角看来, 全球土地使用的平方米中位数, 对于位于该国土地之外、而非之内的人类人口的未来有所贡献。诸多土地连结, 以製造的商品和服务的形式触及我们, 而非仅是透过食品或纤维。我们的结论, 须对所有的商品、活动与地方的间接连结同时进行检视 : 我们对于土地和全球化的特徵描绘, 因而与检视单一商品链的研究或直接贸易统计所使用的证据形式有所不同, 儘管两造的结果经常是互补的。我们显示探讨空间的地理政治经济学和关係性量化方法, 能够对于理解人类世中的土地使用做出大量贡献。 *关键词： 资本, 消费, 全球化, 土地使用, 关係性空间。*

La globalización entrelaza vidas humanas con campos y bosques distantes. En respuesta a eso, nuestro acercamiento a la tierra es relacional, aunque también computacional. Calculamos y cartografiamos conexiones intrincadas entre usos de la tierra y poblaciones distantes mediadas por cadenas de mercaderías y capital, de ese modo desentrañando, profundizando, extendiendo y pluralizando métodos recientes para estimar las huellas dejadas en la tierra por el consumo de mercaderías. Después de construir redes de aproximadamente 130 millones de conexiones directas entre los usos del suelo, las actividades económicas y los pueblos del mundo en 2007, trazamos infinidad de interconexiones indirectas. Los enfoques de espacio absoluto dominante aplicados a las relaciones humano-ambientales facilitan las comparaciones locales de población y recursos, pero nuestro enfoque relacional cuantitativo suministra mapas y medidas que ilustran cómo el desarrollo desigual bajo la globalización neoliberal resulta en fuertes redes de redistribuciones globales de varios beneficios del uso de la tierra per capita, especialmente del Sur Global hacia el Norte Global. Desde la perspectiva de la inversión de capital, la media de metro cuadrado de uso global de la tierra contribuye a los futuros de las poblaciones humanas por fuera, no dentro, del país de esa tierra. Muchas conexiones con la tierra nos llegan en forma de productos manufacturados y servicios, no solo como comida y fibras. Nuestras conclusiones requieren el examen simultáneo de las interconexiones indirectas de todas las mercaderías, actividades y lugares; nuestras caracterizaciones de la tierra y la globalización difieren entonces de las formas de evidencia usadas en estudios que examinan las cadenas de una mercadería individual, o que son ofrecidas por las estadísticas de comercio directo,

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aunque los resultados a menudo son complementarios. Mostramos que la economía política geográfica y los enfoques cuantitativos relacionales del espacio tienen mucho que ofrecer para los entendimientos de la tierra en el Antropoceno. *Palabras clave: capital, consumo, globalización, uso de la tierra, espacio relacional.*

What happens when we see commodities as mediating relationships among distant lands, distant lives, and our everyday existences? There are consequences for how we view commodities but also for how we view land uses, others, and ourselves. Inequalities become relational; we tend to narrate the natural and the social as coconstituted and historical; and we might understand spatiality itself as produced, pliable, and multiple.

Contemporary computation and cartography often provide limited support to such approaches. We frequently must revert and reframe relational geographical understandings of land, commodities, others, and ourselves within dominant ontological commitments of Western modernity to render them calculable, visualizable, and audible in public conversations. Land thereby exists within absolute space, as a collection of localized containers for always-already individuated phenomena. Interactions must play out, first and foremost, in the locale. Setting aside the historical nature of what counts as a resource, thinking in terms of absolute space encourages constructing quantities such as national or local ratios of resources to human population—quantities that facilitate particular geographical narratives of abundance and scarcity.

We address this disconnect by offering a selective synthesis: an approach to land under globalization that is both computational and relational, ontologically prioritizing connection. We map the interconnections among land uses and distant populations mediated by the global economy through commodity chains and the circuits of capital. We do so by constructing networks of up to 130 million relationships, which link land uses, peoples, and economic activities of the world in 2007. We then trace through infinities of indirect connections among peoples and lands using novel approaches to interregional input–output analysis, examining and shifting a terrain of political calculation offered by recent first attempts to comprehensively quantify relations between populations and lands via globalized production and exchange.

We explore several empirical questions from different theoretical perspectives. What patterns connect the lands and labor of particular places with the consumption or fixed capital investment of others? Where are the "globalized" forests, fields, and pastures that contribute to the lives of distant others? How uneven is this globalization? To what extent does local consumption or fixed capital investment depend on the relative abundance of local land resources? When we encounter lands from afar, do we do so through recognizably agricultural or organic objects, such as food and fibers, or are many fields present in factories and in services? How sensitive are the answers to such questions to the standpoint we use to relationally quantify ecological economies?

Finally, we ask what the spatialities of environment are in the Anthropocene, when, to the extent that the human and nonhuman were ever separable, they are now seen as coproduced (Castree 2014). Our approach offers relational quantitative support to views of environment as a profoundly more than local, perhaps even nonlocal, concept. For example, present consumption approaches find global trade "globalizes" only about a quarter of lands (Weinzettel et al. 2013; Yu, Feng, and Hubacek 2013). From our capital perspective, however, the median square meter of land use in the world contributes to the futures of human populations that are outside, not inside, of the country of that land.

Does one need a relational quantitative approach, though, to know that the land is highly globalized given the commodity exchange and production networks of global capitalism, with strong net subsidies from the Global South to the Global North? Those who study, live near, or work in logistics networks have a deep sense of the importance of trade today. We have remarkable studies of individual commodity chains and regions, historically and in the present. Yet at the same time, aggregate statistics of global agricultural production and direct trade flows alone would not immediately suggest such strong globalization as we find. In terms of direct trade, exports are only 14 percent of global cereal grain production.[1] Exports are merely 6 percent of timber production in the form of wood fuel, sawn wood, and roundwood and are just 29 percent of paper and pulp production.[2] Of course, both historical perspective and field research in the Global South make it apparent that primary commodity exports to the Global North play a fundamental role in world political–economic history. Does this suggest, though, that the Global South is a strong net exporter of embodied land to the Global North today, as we find? In fact, despite having some strong net exporters, much of the Global South, including Africa as a whole, is now a net *importer* of agricultural products overall.[3]

Knowledge of direct trade patterns, individual commodity chains, or the export activities of plantations and ports is potentially complementary to, but different in breadth and kind from, the insights a relational quantitative approach to lands, commodities, consumers, and capital yields. In the latter, everything has internal relations with everything else, however unevenly. The first studies recently attempted to examine all global commodities and to comprehensively trace all indirect connections between lands and consumers contained in the chains, webs, and spirals of the global economy. Drawing on geographical political economy, our methods critique, clarify, generalize, and pluralize these recent approaches, yielding detailed portraits of land in motion.

Locating Land in Motion

Geographical understandings of land and its relations to human populations have many antecedents. Scholars have read classical economics and political economy, including work by Ricardo, Marx, and von Thünen, for theoretical insights into the roles played by land and space, often through the mediations of rent (Sheppard and Barnes 1990). The production of space and the production of nature are interwoven, yielding restless and unevenly developing landscapes (Smith 1984; Harvey 1996). Spatial divisions of labor are also ecological relationships. The town–country "metabolic rift," from Marx's account of urbanization and agricultural change disrupting nutrient cycles, has deepened and extended (Schneider and McMichael 2010; Moore 2011). World-ecological approaches understand (spatially intensive and extensive) socioecological relations not as external relations between society and nature but as internal relations to a dialectical dynamic (Moore 2015).

Many studies in political ecology examine the shaping and roles of landscapes in globalization, work that is both theoretically informed and often expressive of extensive experience in the field (Rocheleau, Thomas-Slayter, and Wangari 1996; Robbins 2011). Nonlocal connections and power relations have featured in explanations of soil degradation and the accumulation of landesque capital alike (Blaikie and Brookfield 1987; Håkansson and Widgren 2014). Researchers have placed localized understandings of deforestation into broader sociospatial context and historicized them (Jarosz 1993; Lye, De Jong, and Abe 2003). There is "ecologically unequal exchange" among different parts of the world, in which international trade unevenly distributes environmental benefits and costs to countries of the Global North and Global South (Hornborg 2003; Jorgenson 2006), providing an alternative to the absolute spatiality of neo-Malthusian arguments around population pressure. Generally, scholars have associated waves of accumulation through dispossession, commodification, and shifting regulation at all scales, including international trade regimes, with a resurgent neoliberalism that underpins the extensive globalization of the benefits to land we study here (Harvey 2005; Heynen et al. 2007). In what follows, we bring critiques of neoliberalism, which often direct attention toward capital and shifting dynamics of accumulation, into conversation with current approaches to land footprints ontologically centered on individual consumption (which can be consonant with a "green" neoliberalism itself; Bakker 2010).

Land-system science has emerged as a banner under which human–environment research occurs in related, but different, sets of conceptual, empirical, and institutional milieus (Turner and Robbins 2008; Verburg et al. 2013). Many studies have examined richly interacting human and environmental processes at multiple scales, generalizing findings for insight into critical debates around the interactions of land use and land cover change with the dynamics of populations, goods, and capital (DeFries et al. 2010; Lambin and Meyfroidt 2011; Meyfroidt et al. 2013). A National Research Council (2010) report challenges researchers to consider how "changing consumption patterns, regulations, and costs in one place affect farming systems, land use, and food security in other places" (64) in its "Strategic Research Questions" for the geographical sciences. Seto et al. (2012) called for the study of "urban land teleconnections" between land uses and (often distant) urbanized populations (see also Liu et al. 2013). Deeper investigations of trade connections are important to furthering understanding of local environmental outcomes.

Indeed, within land change approaches and human–environment science more generally, recent years have seen the rapid development of empirical research quantifying the spatial relations between consumers and associated environmental changes (Henders and Ostwald 2014; Schaffartzik et al. 2015). Often, this research suggests a consumption-based accounting approach, in which we no longer simply account for or map environmental burdens according to the absolute spatial location in which those burdens occur but assign them to the locations of the associated consumers whose consumption directly and indirectly required those burdens (whether emissions, land use, deforestation, etc.; Wilting and Vringer 2009). Spatially explicit versions of the ecological footprint (Moran et al. 2009) might be the most widely known examples, quantifying the areas of land that would be needed to produce ecological goods and services appropriated, directly and indirectly, in either the production of a product or the overall consumption of individuals or populations. Other important approaches include spatial studies of the human appropriation of the net primary productivity (HANPP; Haberl et al. 2009) through use of biomass. Erb et al. (2009) found that HANPP travels internationally in biomass-related products (12 percent of global HANPP was embodied in net flows among countries in 2000) and tends to be traded from areas of low to high human population density.

The most broadly comprehensive studies quantifying the economic and geographic connections between land and populations generally employ environmentally extended interregional input–output analysis (Miller and Blair 2009; Wiedmann 2009). Such approaches require the compilation of data on how different economic activities in different regions directly depend on each other's outputs as their inputs to production. Input–output analysis then uses linear algebra to infinitely trace the commodity chains and circuits of capital that relate a given activity or commodity with all of the activities elsewhere in the world (e.g., land use or pollution) that directly *and indirectly* enabled it. Studies find strong globalization of carbon emissions from combustion; estimates of the fraction supporting economic demands of countries other than where the emissions occurred range from 20 to above 50 percent, depending on the underlying sociospatial perspective taken (Davis and Caldeira 2010; Bergmann 2013). Recently, researchers have adapted some such methods for the study of indirect connections between land uses and distant consumers (Weinzettel et al. 2013; Yu, Feng, and Hubacek 2013), suggesting that approximately a quarter of lands are globalized. Weinzettel et al. (2013) found embodied land exports are associated with high per capita endowments of biomass productivity, whereas affluence conditions the geography of imports.

Although such existing methods suggest that approximately a quarter of lands are globalized, we show that other input–output modeling perspectives, such as a more focused consumption perspective or a capital footprint approach, reveal that up to a majority of lands are already globalized. Further, in contrast to such previous studies, there is a very strong net subsidy from the Global South to the Global North and a lesser role for territorially based understanding of resource endowment and scarcity in determining the global geography of embodied land flows. We rely on geographical political economy (Sheppard 2011; Bergmann 2013) to develop our constructive critiques of past methodological assumptions, offering one response to Munroe et al.'s (2014) call for "using economic geography to reinvigorate land-change science."

That assumptions can matter to results is not surprising. Of greater interest is how sensitive results are across different plausible assumptions. We offer the first exploration into the consequences of various theoretical assumptions (and of alternatives we contrast them with) for how we perceive global relationships between lands and consumers. In doing so, we explore differences in the politics of calculation consonant with our different mathematical approaches (Crampton and Elden 2006; Freidberg 2014), revealing how agricultural landscapes change when seen through the lenses of which consumers versus of what capital investment they support. We work at different scales, with different mathematical frameworks and with somewhat different objects of analysis, that nonetheless complement emerging work in geography and Science and Technology Studies that explores how system boundaries and spatial granularity matter for life-cycle assessments (LCAs) that quantify the footprints of individual products and resource flows (Newell and Vos 2011; Cousins and Newell 2015).

Why do different input–output assumptions lead to substantially different understandings both of how globalized the land is and of what (unequal) spatial relations are associated? There are unavoidable mathematical trade-offs in open Leontief input–output modeling between, on the one hand, the type and breadth of commodities that can have their footprints measured and, on the other, the type and the comprehensiveness of the connections among people, places, and activities that can be traced in measuring those footprints (Bergmann 2013). Different modeling perspectives use different divisions between which commodities or activities are "endogenous" to the input–output model and that compose "exogenous" demand. This distinction is important but surprisingly subtle; in global environmental input–output modeling approaches (contra LCA and single commodity footprint approaches), no matter where the divisions are drawn between exogenous and endogenous, all global lands used agriculturally will still be accounted for and related to distant populations, although the degrees and distributions of spatial relations will differ. Enforcing an accounting assumption, there can be no "double counting" or undercounting of lands; one given point of land is always ultimately allocated to one single commodity in the (exogenous) demand of a population and, thus, with one region.

Different divisions between endogenous and exogenous do imply two interrelated shifts. First, the theoretical interpretation (and empirical values) of given footprints and of overall spatial relations change. The decision about which activities are exogenous is a necessary decision about the lens through which we will view global land use; for example, associating land with household consumption in one region versus in another; with capital investment; or with another set of activities, whether broader, narrower, or overlapping. Second, though, that decision is also tied to shifts in which connections among activities and commodities are mathematically visible (or invisible) and are thus able to be traced upstream to locate land uses embodied in a product. In finding the footprint of a commodity or activity, only connections among endogenous commodities and activities can be traced and included, if there is to be no "double counting" (Bergmann 2013; again, unlike most LCA). Each modeling perspective thus renders certain connections invisible and irrelevant in the process of foregrounding others. The broader the set of commodities and activities that are having their footprints measured in understanding the global connections among lands and peoples, the shallower those footprints must be, with implications for the resulting patterns and degrees of relations.

Let us consider one example of how the division between the endogenous and exogenous can matter. A worker assembles goods for export from the Pearl River Delta in southern China and consumes a bowl of rice. Should we associate the land use footprint in the rice paddy with the worker's consumption (and with China)? Or should we associate it with the good (and with the West, assuming that is the region of use), given that the production of the good required the labor power of the worker? If consumption (and thus the reproduction of labor power and the necessities of the household) is endogenous—as in the type of capital footprint perspective offered later—then the latter holds. If only consumption is exogenous, the former holds. Yet in previous studies of land and globalization, not only consumption but all of final demand (which includes household consumption, capital investment, and government expenditure, among other categories) has been exogenous, which complicates the matter further. The decision of how to associate paddy land use with its ultimate beneficiaries is then quite sensitive to certain conditions of the factory that otherwise might appear arbitrary from the perspective of socionatural analysis. If the factory provides the meal, the footprint follows the good. If the worker was given the monetary equivalent and brings food or buys a meal outside the gate, then the footprint stays with the worker.

How could whether or not the worker purchases her lunch directly have become a type of factor that significantly shapes our understandings (as we show later) of the global geography of footprints and of the economic globalization of environmental issues? Decisions made within a historical and social milieu quite distinct from that of the present concerns around environment and globalization have unintended, and often unexamined, consequences for which connections will be traced (and how) within footprint calculations. Modern input–output techniques and national income accounting developed together in the early and middle twentieth century (Kuznets 1941; Leontief 1951). Kuznets, a key originator of the concepts and details of national income accounting, was clearly keenly aware of the ambiguities in play. Ultimately, however, he wrote, "Essentially, we are interested in the type of national income we estimate because it corresponds broadly to current social philosophy, evolved from the basic assumptions of the modern social structure" (Kuznets 1941, 37). Understanding national income and final demand as socially situated concepts might sit uneasily with claims that they form part of a singular basis for scientific decision making about socionatural systems whose length and time scales easily extend to the planetary and the millennial. In one dilemma Kuznets (1941) explored, the differentiation of activities into being intermediate and final is by no means simple to resolve. Despite claims that we use national income accounting, consumption, he noted, has been left expressed partially as a gross, not net, concept. Whether because of the difficulty of constructing an efficient and unambiguous set of measures with the existing statistical apparatus or a lack of congruence with preferred understandings of the prevailing social philosophy, work-related expenses on the part of workers (likely including the hastily eaten bowl of rice just imagined) were left accounted as national income and not as intermediate inputs, as they would have been if they were commodities used in the production process in industry.

The various decisions made by Kuznets and his colleagues given a situated understanding of "current social philosophy" need not be those most appropriate to quantifying embodiments of land use. Indeed, from the beginning of Leontief's input–output formulations, there has been recognition that the manner in which models are closed is critical and needs to be decided according to the issue at hand. Choosing (a socially situated notion of) final demand to be exogenous in the quantification of footprints is only one choice. We demonstrate the degree to which several sets of reasonable assumptions associated with particular implicit understandings of the socioecological roles played by commodities lead to different understandings of land, commodities, capital, populations, and their interrelations.

We consider three approaches, whose perspectives we term final demand, consumption, and capital investment. Our final demand modeling perspective holds as exogenous the (aggregation of the) three final demand categories offered by the Global Trade Analysis Project (GTAP) database: consumption, investment, and government (more detail is given in the next section). Terminological ambiguities then arise. What we term a final demand model is usually what has been used by research that labels itself as doing consumption-based accounting. Yet our clarified consumption model differs significantly from the final demand model, as our consumption model endogenizes the unrelated investment and government sectors. Thus, the commodity chains linked to those latter sectors can be traced and included in a more comprehensive sense of the footprints associated with products. Similarly, we contrast these with a capital investment perspective derived from endogenizing the sectors and (tracing the) commodity chains associated with the reproduction of the household and labor power.

Our consumption and capital investment perspectives are neither merely components nor subsets of the final demand approach commonly used today for estimating consumption footprints and their globalization. Instead, for each commodity, they not only each trace more supply chain connections than is possible in the final demand perspective but, in doing so, they also remove the blurring of socioecological roles that occurs in the final demand model. A product considered from the perspective of its potential role as a consumption good plays different socioecological roles than the same good considered as a potential capital good (e.g., a kilowatt-hour of electricity used to light a home vs. to build a power plant). Consumption goods are extinguished in the present, contributing to the reproduction of the household today, whereas capital goods are a promise to the future at geographic, temporal, and ecological scales that are broader than the household but narrower than any imagined totality of an unevenly developing planet. Our consumption and capital investment models embody such role distinctions, but the conventional final demand model for consumption cannot.

Expanding, deepening, and interpreting footprints, we also contribute to recent efforts to realize a political-industrial ecology (Newell and Cousins 2015). In each of these perspectives, not only do we change which roles of products can be quantified but we consequently indirectly change the underlying quantifications of the footprints associated with products themselves. We demonstrate that neither the quantification of commodity footprints nor associated aggregated understandings of the globalization of land are singular or universal, but each is plural and situated with respect to both a particular set of questions and the "current social philosophy" (see Haraway 1988). We return to the theoretical and social implications of this observation in the Conclusion.

Before discussing the details of methods and the insights of results, however, it is worth reflecting more on the partial, yet complementary, politics of the perspectives offered by the two new approaches to land here. To help us do so, let us return to our thought experiment centered on understanding a product exported to the United States from the Pearl River Delta of China. There, many workers are migrants from distant provinces and from less urbanized environments. Export-oriented growth has thus been associated with shifts in the composition, level, and geographical sources to demand for consumption. Taking a consumption-based approach to accounting for the land embodied in exported products might be seen to emphasize both the agency that workers assert in coming to work along the coast and the fact that workers are living their own lives and contributing to their families, not merely "reproducing labor power." Land use would thus be attributed to workers and to China. Alternatively, taking an investment-based approach emphasizes that the being and becoming of the Pearl River Delta has also been part of greater shifting geographical political economies in which capital and investment have been important determinants. Associating the land use embodied in products with the locations where the capital investment occurs that those products facilitate further acknowledges that workers live and consume differently in the Pearl River Delta, not only out of free choice but also out of a lack of adequate alternatives in the regions of their youth, spending much of their time in production processes that contribute indirectly but significantly to building the economic futures of distant places. Both modeling approaches speak to important truths, but neither is satisfactory alone. We need the results of both these models, among others, to develop nuanced, plural understandings of the roles of land in the contemporary capitalist world-ecology.

Toward a Relational Quantitative Geography of Land in Motion

To sketch the complex topologies of metabolic rifting among peoples and landscapes within contemporary capitalist world-ecology, we trace economic connections between forests, croplands, pastures, and (often distant) persons of the world. Tracing chains in what rapidly becomes an imaginary of infinite depth and breadth of branching and spiraling requires a relational quantitative approach to acts of production, consumption, and exchange.

In this article, we therefore construct a global interregional social accounting matrix (SAM; Miller and Blair 2009), a superset of the global multiregional input–output table required by existing consumption-based accounting studies of land. A global interregional SAM assumes a comprehensive partitioning of the global economy along two dimensions into a set of regions and into a set of economic activities. For a given year, it then records how much of any given activity produced in any given place is used to produce a single unit of any other activity (often a good or a service) in any other place. Most commonly, these quantities are recorded in units of money. A SAM often also records the flows of goods, services, and money in and out of special parts of the economy, including transportation services that produce accessibility, households that consume and reproduce labor power, fixed capital accumulation and investment, and governments. It is possible to supplement such a SAM with information regarding how much land, of what type, and in what places is needed, on average, to realize any of the economic activities recorded earlier. At that point, one could trace the infinite webs that link lands to often-distant consumers or capital investment, as we show later.

We build our global interregional SAM using the GTAP 8.1 database from the Global Trade Analysis Project headquartered at Purdue University (Narayanan, Aguiar, and McDougall 2012). Researchers often use GTAP databases for computable general equilibrium modeling of global trade scenarios, yet most of the consumption-based accounting studies cited earlier have reappropriated it.[4] The approach we follow in constructing our global interregional SAM, **S**, is based on the one Bergmann (2013) developed. In brief, those methods reconcile McDonald and Thierfelder (2004)'s insights into constructing single-country SAMs from GTAP 5 and 6 data with Rodrigues, Domingos, and Marques's (2011) approach to creating interregional input–output tables from GTAP 6 data and then generalize the approach to construct global interregional SAM tables. Here, we also leverage the advances of the GTAP 8.1 database, which allow us to construct SAMs for 2004 and 2007, which was the most contemporary data available and records a historic period of neoliberal globalization (Harvey 2005). Each of these SAMs accounts for the transactions among eighty-five economic activities (spanning a broad conception of the economy, from producing wheat and financial services to reproducing labor power) within and between each of 134 regions and countries that subdivide the land surface of the world, for a total of up to approximately 130 million flows per SAM.

We then link the activities within these networks to landscapes at a much finer grain. The GTAP-AEZ satellite dataset for GTAP 8.1 (Baldos and Hertel 2012) disaggregate land inputs required by a sector into relative shares across up to eighteen agroecological zones (AEZs) within each region (Appendix A). Whereas SAMs in Bergmann (2013) have sixty-eight sectors per region, our regions each have eighty-five sectors because we subdivide the "land" sector. The AEZs are combinations of six lengths of growing period with three climatic regimes, based on research by the United Nations Food and Agriculture Organization (FAO) and the International Institute for Applied Systems Analysis (IIASA; Lee et al. 2005). Further, only certain sectors use land harvests as direct inputs, with Sectors 1 through 8 using croplands, Sectors 9 through 12 requiring pastures, and Sector 13 relying on forested lands (see Appendix B). From the GTAP-AEZ data set, we also draw aggregate quantities of harvested area within each land type, AEZ, and region. Finally, GTAP-AEZ provides half-degree resolution global gridded datasets of the fractions of each cell occupied by each different land use. As a result, within each country, within each given AEZ, within each of the three land uses considered, we know how much land was directly required as input to produce one unit of a given GTAP product. By calculations detailed later, we are then able to offer the first maps with subnational detail on where and how lands are globalized by the relations of neoliberal globalization.

Tracing Transnational Teleconnections Among Lands and Peoples

To trace both direct *and indirect* connections between land and consumers through all possible intermediate steps in global commodity chains, we employ the computational linear algebra of input–output analysis. For each AEZ a and land use type l, define a land use intensity vector, ${}_{al}\mathbf{f}$, whose entries ${}_{al}f_n^j$ are the number of hectares of land whose products are required as direct inputs for each dollar of output from sector n in region j. We calculate those ${}_{al}f_n^j$ as follows:

$$ {}_{al}f_n^j = \frac{{}_{al}LCOV^j}{x_n^j} \frac{{}_{a}VFM_n^j}{\sum_o {}_{a}VFM_o^j}. \tag{1} $$

Here, ${}_{al}LCOV^j$ and ${}_{a}VFM_n^j$ are drawn from the GTAP-AEZ satellite data set, with the former being the areas of land use of a particular type, l, within a given AEZ, a, appropriated in a specific region j and the latter being the land rent paid by a particular sector, n, in a region, split among the relevant AEZs. The total output of sector n in region j is x_n^j, as given in Bergmann (2013). The expression takes the *LCOV* land area in the AEZ and allocates it to a given sector by the share of the land rents paid within that AEZ in that sector compared to other sectors in the region. Division by the total output of the sector in the region normalizes the expression so that the land intensity is given in terms of appropriated area per unit output. This method implicitly approximates the cropping frequency to be the same within a given agroecological zone in a given region. It also denominates results in hectares and square kilometers, aiming for a broad commensurability with geographic scholarship.

To produce a dollar of output from activity n in region j, one can find the total areas of land (under land use l, associated with [agricultural] activity m, in AEZ a, in region or country i) whose products were required by calculating the Leontief inverse matrix, ${}_{al}\mathbf{L}$, whose entries are ${}_{al}L_{mn}^{ij}$ (Leontief 1986). By environmentally extended open Leontief analysis (Miller and Blair 2009),

$$ {}_{al}\mathbf{L} = {}_{al}\hat{\mathbf{f}}[\mathbf{I} - \mathbf{A}]^{-1}. \tag{2} $$

Such a calculation traces out and sums up the contributions made by inputs to a commodity, the inputs to those inputs, and so on, infinitely, in commodity chains, including recursive loops (e.g., a wheat farm worker might eat bread). Yet these sums are finite; the endlessly proliferating contributions nonetheless diminish in magnitude the farther they are from the product in question. In Equation 2, ${}_{al}\hat{\mathbf{f}}$ is a diagonalized matrix of ${}_{al}\mathbf{f}$, $\mathbf{I}$ is an identity matrix, and $\mathbf{A}$ is a square matrix whose entries A_{mn}^{ij} record in dollars how much input from activity m in region i is directly required to produce a dollar of output in activity n in region j. In practice, the entries for $\mathbf{A}$ are drawn from the global SAMs we described earlier.

As described previously, this article examines how planetary land use may be understood from multiple, partially incommensurate, perspectives. Operationalizing any one of the final demand, investment, or consumption perspectives is a matter of determining which sectors (rows and columns) of the SAM $\mathbf{S}$ are endogenous to the input–output model and are thus included in $\mathbf{A}$ versus those that are exogenous and are thus included in demand vectors, $\mathbf{y}$ (see Bergmann 2013). In the final demand model, $\mathbf{A}$ includes all sectors in each region except those corresponding to household consumption, government demand, and fixed capital investment. The demand vector $\mathbf{y}$ for a given region is the aggregate of these excluded sectors. In the consumption and investment models, by contrast, $\mathbf{A}$ includes all sectors except the household consumption and fixed capital investment in each region, respectively. Sector definitions can be found in Appendix B.

If y_n^{ij} are the dollar amounts of activity or commodity n directly required from region i to realize demand in region j, then, to calculate ${}_{al}C_{ij}$, the area of land use l appropriated in AEZ a of region i that ultimately supports demand $\mathbf{y}$ in region j, let

$$ {}_{al}C_{ij} = \sum_{m,n} \left({}_{al}L_{mn}^{ij} \, y_n^{ij} \right). \tag{3} $$

All the calculations that we use in this article rely on ${}_{al}C_{ij}$ that have been calculated at the finest level of detail (in terms of sectors, regions, and AEZs) in the dataset described earlier. Then, as appropriate, results have been aggregated for the purposes of analysis or visualization. For example, aggregating distinctions between agroecological zones yields expressions of overall interregional interdependence between lands and the activities of $\mathbf{y}$:

$$ {}_{l}C_{ij} = \sum_a \left({}_{al}C_{ij} \right). \tag{4} $$

Figures 1 and 2 visualize these spatial patterns linking land to demand but at a higher level of territorial

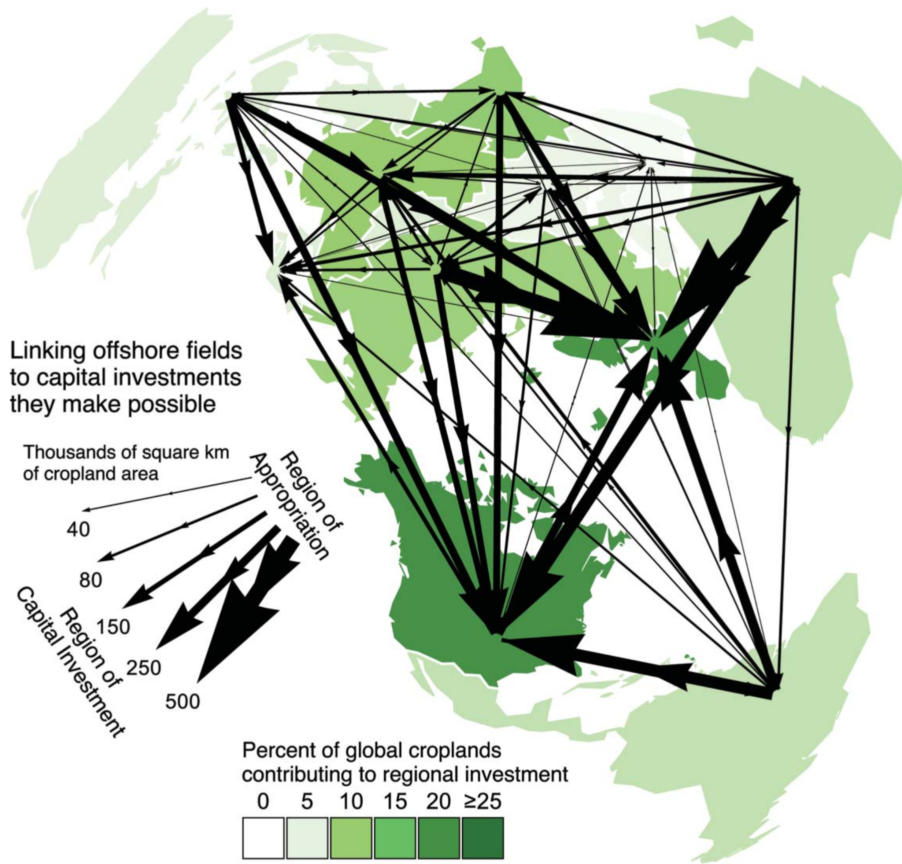

Figure 1. Relations between the locations of land use and the capital investments that are eventually supported by those lands in 2007. Lambert Azimuthal equal-area projection. (Color figure available online.)

aggregation, the macroregions of which are described in Appendix C. Note that these flows are not the land use embodiments directly of the particular goods traded between pairs of locations but the land use embodiments to the total direct and indirect interactions between territories, regardless of intermediate paths and commodities involved.

The Globalization of Fields and Forests

For each land type l within a given AEZ a and region i, we can estimate what fraction of the appropriations from that land use indirectly and directly support demand outside region i, ${}_{al}G_i$, by letting

$$ {}_{al}G_i = \frac{\sum_j \left({}_{al}C_{ij}\right) - {}_{al}C_{ii}}{\sum_j \left({}_{al}C_{ij}\right)}, \quad (5) $$

where $\sum_j \left({}_{al}C_{ij}\right)$ is the total amount of land of type l within the AEZ a of region i and ${}_{al}C_{ii}$ is the amount of land in this subregion supporting domestic demand. Table 1 summarizes the results at a global scale, calculating the degree to which lands have been "globalized." The degree to which demand in world regions is dependent on land in other regions, implying that land is globalized, is a function of the level of territorial (dis)aggregation being considered. If the interregional interdependence matrices **C** are aggregated to a single world region, no land is globalized. In a world of regions so finely divided that there are several regions per field, the degree to which lands are globalized approaches 1. For a given regional aggregation of the interregional interdependence matrices **C**, let

$$ {}_{l}G = \frac{\sum_{ij} \left({}_{l}C_{ij} - {}_{l}C_{ii}\right)}{\sum_{ij} \left({}_{l}C_{ij}\right)}. \quad (6) $$

Yet not all parts of the landscape are equally significant as producers. We therefore produce three separate gridded data sets with values at a given

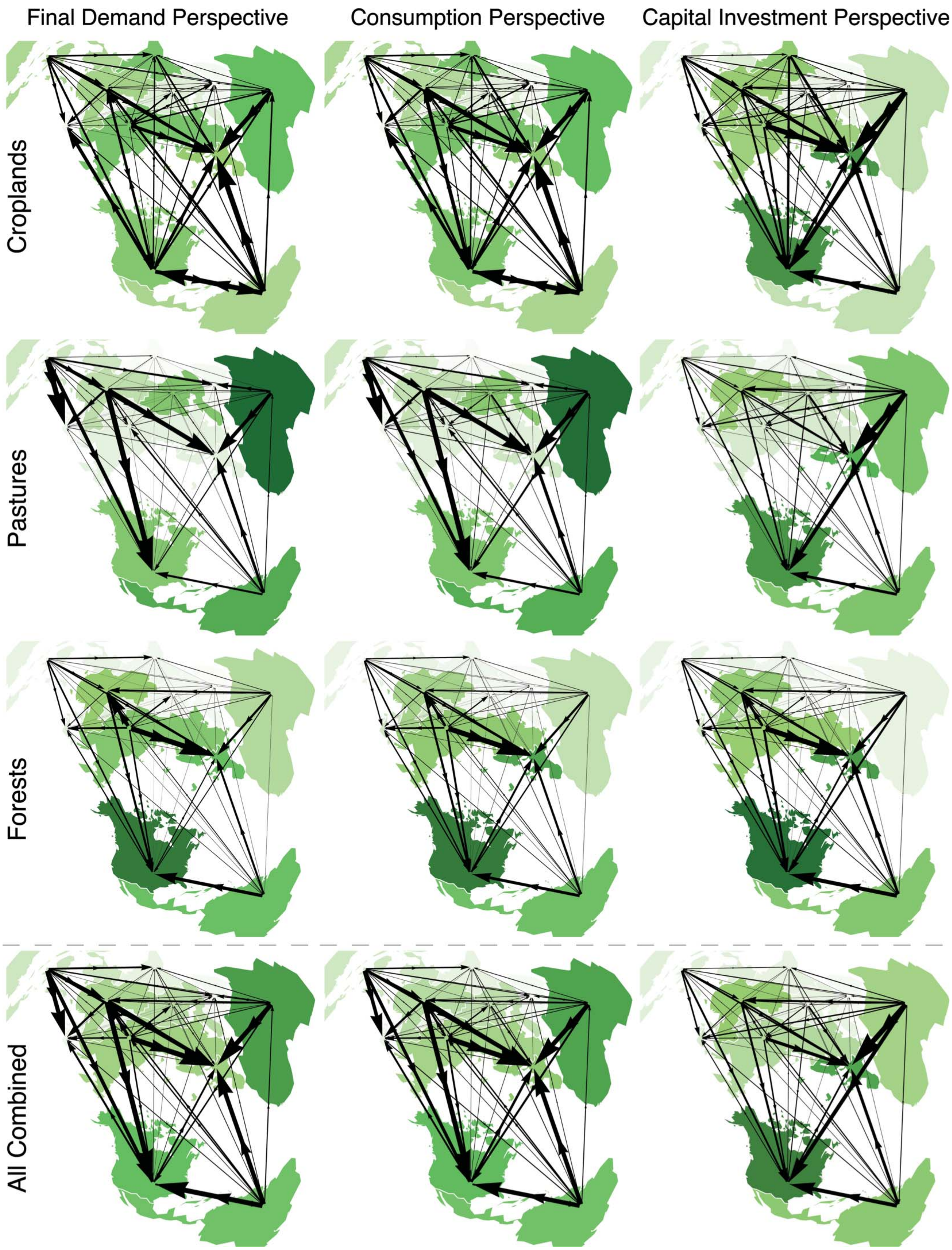

Figure 2. Relations between land use and demand across different land uses and modeling perspectives in 2007. The meaning of shadings and connections are similar to those in Figure 1, with the exception that the thickness of relation arrows is rescaled proportionally to the relation of greatest magnitude in each map. (Color figure available online.)

Table 1. Percentages of land "globalized" in 2007 as understood through various perspectives and at different scales of regional aggregation

		Land type			
	Perspective	Croplands	Pasturelands	Forests	Overall
129 Regions	Consumption	29	23	49	32
	Capital investment	61	59	58	59
	Final demand	25	19	38	26
11 Macroregions	Consumption	23	18	40	26
	Capital investment	54	53	48	52
	Final demand	20	14	30	20

point (x, y) that subdivide the global land surface into three fractions: (1) the fraction of the landscape of human-appropriated forests, fields, and pastures that is globalized ($P^{\text{global}}_{l,xy}$); (2) the fraction that is localized ($P^{\text{local}}_{l,xy}$); and (3) the remaining fraction of the landscape that is in other types of land use or land cover not examined here, such as urbanized lands or ecosystems not directly appropriated through the means considered in this article ($P^{\text{non}}_{l,xy}$). At any point, by definition, $\sum_l \left(P^{\text{local}}_{l,xy} + P^{\text{global}}_{l,xy} + P^{\text{non}}_{l,xy}\right) = 1$.

To calculate these distributions, we first need measurements of spatial grids $\mathbf{P}_l$ with values $P_{l,xy}$ that are the fractions of the landscape area occupied by land uses l at points (x, y) subject to the constraints $\sum_l P_{l,xy} = 1$ and $P_{l,xy} = P^{\text{local}}_{l,xy} + P^{\text{global}}_{l,xy} + P^{\text{non}}_{l,\,xy}$. We also need knowledge of the fractions of land uses l at points (x, y) with harvests that are directly appropriated into market exchange within the present capitalist world-ecology, $h_{l,xy}$. As a first approximation, take the fraction of land in use l at a point (x, y) that is globalized to be the value of the fraction of globalization calculated earlier, $\mathbf{G}$, in the corresponding AEZ, a_{xy}, and the corresponding region, i_{xy}: ${}_{a_{xy}l}\mathrm{G}_{i_{xy}}$. Thus,

$$
\begin{aligned}
P^{\text{global}}_{l,xy} &= \left(P_{l,xy}\right)\left(h_{l,xy}\right)\left({}_{a_{xy}l}\mathrm{G}_{i_{xy}}\right),\\
P^{\text{local}}_{l,xy} &= \left(P_{l,xy}\right)\left(h_{l,xy}\right)\left(1 - {}_{a_{xy}l}\mathrm{G}_{i_{xy}}\right),\\
P^{\text{non}}_{l,xy} &= \left(P_{l,xy}\right)\left(1 - h_{l,xy}\right).
\end{aligned}
\tag{7}
$$

We examine, compare, and contrast resulting maps of land globalization in Figure 3. In this study, the basis for our land use data is land use and land cover data for $P_{l,xy}$ from Baldos and Hertel (2012), based on updated land use data and past GTAP-AEZ land use satellite data sets and methods (Ramankutty and Foley 1999; Lee et al. 2005; Ramankutty 2011). For croplands and pasturelands, the land cover categorization is also a land use category; we are able to assume that the croplands and pasturelands measured were all appropriated by humans: $h_{\text{croplands},xy} = h_{\text{pastures},xy} = 1$. We handle forested lands differently, as underlying GTAP-AEZ data rely on a land use perspective, whereas the gridded data on spatial distributions provided by GTAP-AEZ represent forested land as a land cover independent of the degree or type of direct human use. Data on human uses of forested lands are scarce. We adapted the methods used by Erb et al. (2007) to estimate a forested land use data set from a land cover data set. We assume that all areas where the human footprint was greater than 1 in the 2005 Global Human Footprint Dataset (version 2) from the Last of the Wild Project (Wildlife Conservation Society and Center for International Earth Science Information Network 2005) are candidates for the economic use of forests. Assigning these cells the value of 1 and all other cells the value of 0, we reduced the resolution of the gridded data set from 1/120 to 1/2 degree to match the other land use data, taking the mean of the 3,600 values from the finer resolution data set within each 1/2 degree cell. We use this result as $h_{\text{forests},xy}$ in Equation (7), estimating local and global forests. Note that in this study, the accuracy of this estimation procedure affects only the visual spatial distributions of forested lands, not the magnitudes of their globalization or their interrelations with other regions.

Thinking Beyond Food, Fuel, and Fibers: Indirect Pressures on Landscapes from Globalization in Manufacturing and Services

To understand the interrelations between consumers and capital, on the one hand, and agricultural land uses, on the other, it is important to study trade

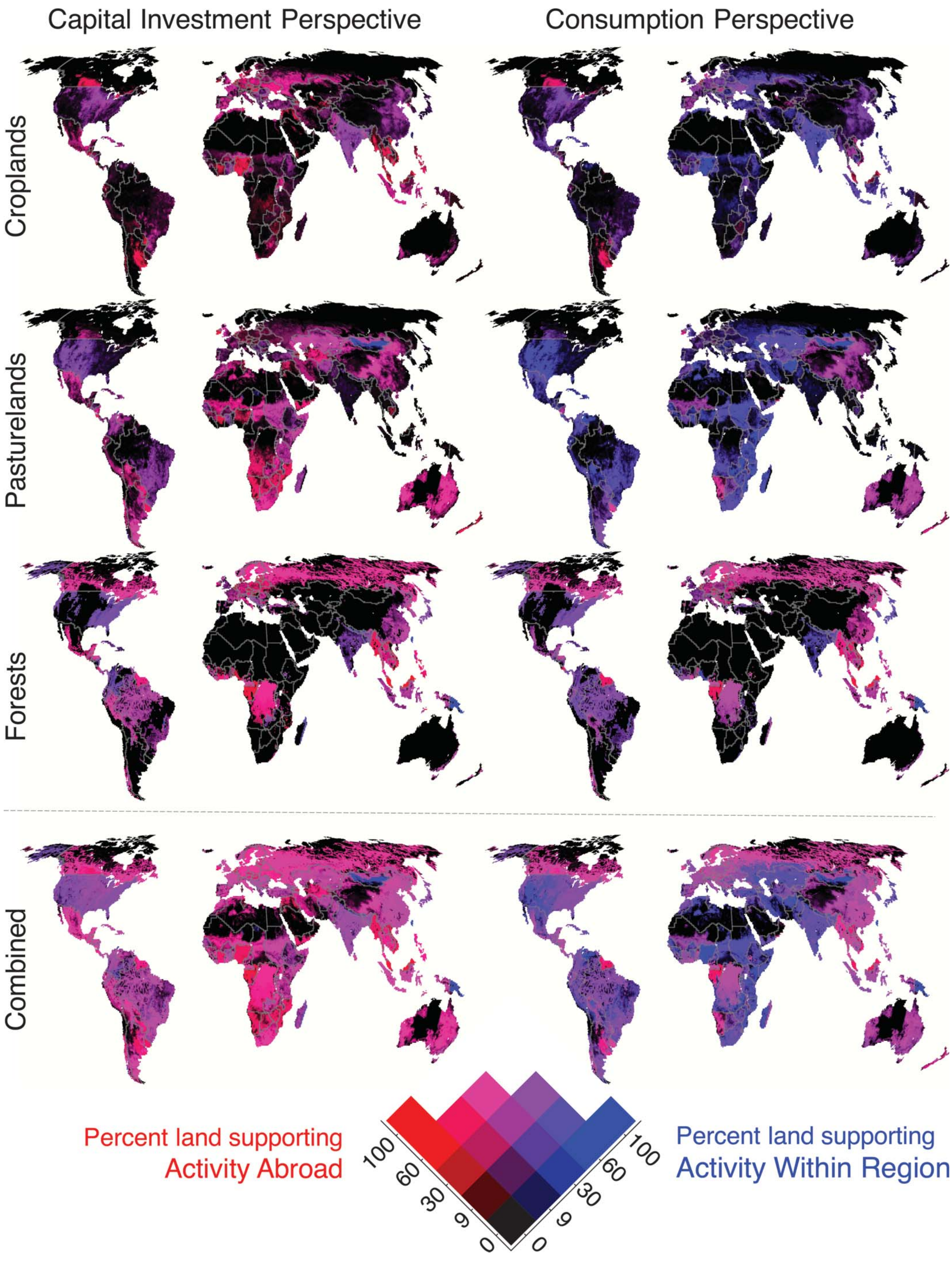

Figure 3. Different perspectives on the globalization of lands in 2007. Eckert IV projections. (Color figure available online.)

flows of commodities that are intuitively related to agriculture, such as food, biofuels, and fibers. But to what extent might the consumption of manufactured goods or services connect an individual to distant agricultural lands? We examine the relative contributions to land footprints from the products in two categories that subdivide demand: agricultural and other primary products, both raw and processed, versus manufacturing and services. The broad notion of agricultural commodities we use includes GTAP Sectors 1 through 37, ranging from those activities that produce raw organic matter directly from the three land uses we examine in this article with a minimum of processing (e.g., wheat, oil seeds, wool, and forestry) to products that are recognizable for their origins in primary sectors but have been further processed (including meat products, apparel, and paper) to also include primary extractive industries and their products. The manufactured goods and services category includes GTAP Sectors 38 through 57 and other SAM sectors, from vehicles to electricity to insurance. This allows for a clear comparison between the extent to which agricultural lands are globalized via agricultural product categories that have been more conventionally associated with the direct products of such lands versus the agricultural lands that are globalized through their eventual contributions to manufacturing and services. Full descriptions of these categories and the sectors that they encompass are available in Appendix B.

What percentages of croplands (or timberlands or pastures) are connected to the final consumption of each of these categories of commodity? For a given such category, called q, whose sectors are members of sets S_q, let us calculate ${}_{al}C^q_{ij}$: the amount of land in use l in AEZ a of region i needed to support consumption in region j of commodity category q:

$$ {}_{al}C^q_{ij} = \sum_m \sum_{n \in S_q} \left({}_{al}L^{ij}_{mn} \, y^{ij}_n \right). \qquad (8) $$

Thus, ${}_{al}C^q_{ij}$ is a fraction of the overall relationships ${}_{al}C_{ij}$ calculated in Equation 3. By construction, $\sum_q \left({}_{al}C^q_{ij} \right) = {}_{al}C_{ij}$. If ${}_{al}C^q_{ij} / {}_{al}C_{ij}$ is a large fraction, then lands embodied in commodity category q constitute a large share of the dependence of consumers in region j on the lands of region i. The values of ${}_{al}G_i$, ${}_{a_{xy}l}G_{i_{xy}}$, $P^{\text{global}}_{l,xy}$ and $P^{\text{local}}_{l,xy}$ corresponding to given categories q can be calculated by substituting ${}_{al}C^q_{ij}$ for ${}_{al}C_{ij}$ in Equations 5 and 7. We can then evaluate the extent to which aforementioned existing debates in the literature regarding the linkages between land use and economic globalization, which tend to focus on trade in agriculturally related commodities such as food and biofuels, might need broadening to consider rising trade in manufactured goods and services. In Figure 4, we therefore present the first detailed portrait comprehensively exploring how different dimensions of the global economy relate to agricultural lands and ecosystems through direct and indirect economic exchange and production, not just how agricultural commodities relate directly to agricultural land use.

Empirical Perspectives on Land in Motion

The percentages of global lands that support human demand outside of their regional territories, and therefore have been "globalized," can be found in Table 1. The amount of croplands the production of which we consider to have been globalized from the final demand perspective in 2007 is 25 percent and, although not shown in Table 1, we likewise calculated as having been 26 percent in 2004, the time period for which Weinzettel et al. (2013) estimated the figure of 24 percent. Similarly, from a final demand perspective on a broader set of anthropogenic lands, Yu et al. (2013) estimated the globalization of croplands, pasturelands, forests, and artificial surfaces to have been 27 percent in 2007, whereas we estimate 26 percent for the same lands except artificial surfaces. Our construction of our SAM data set and implementation of analytical methods are able to corroborate existing results from the literature.

When we trace a greater depth and breadth of commodity chains, however, as in our consumption and investment perspectives on global land use, footprints, and roles of commodities change, the globalization of lands increases significantly. From having 25 percent of cropland being understood as having been globalized from the final demand perspective, 29 percent is from the consumption perspective, and a full 61 percent of worldwide croplands is seen as globalized from the capital investment perspective. Pasturelands and forestlands are similar, although forestlands are already 38 percent globalized in the final demand perspective, rising to 49 percent globalized in consumption. Overall, combining the different lands, whereas 26 percent of the world's agricultural land is considered globalized by the traditional final demand perspective on

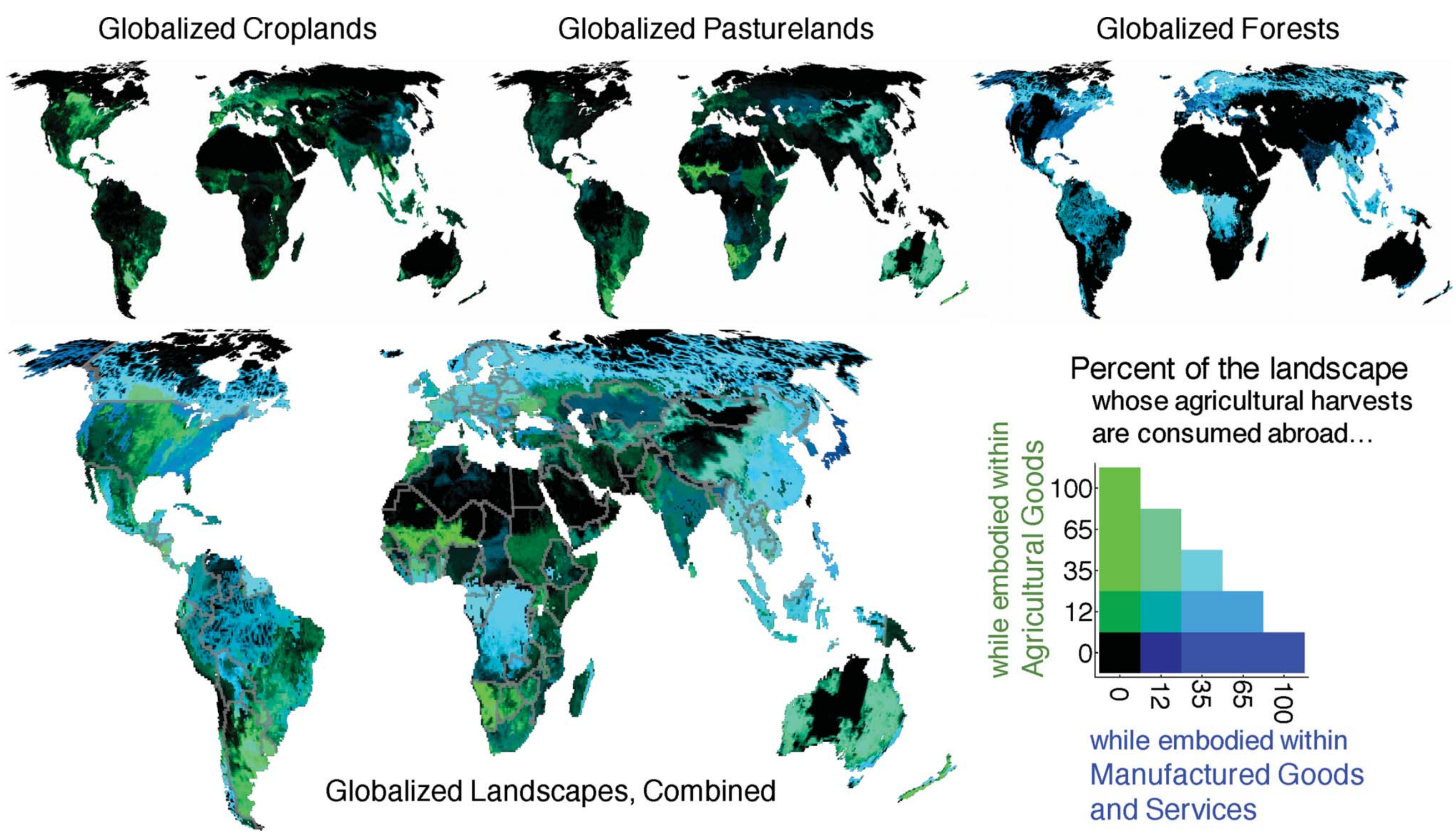

Figure 4. Relative roles played by agricultural commodities versus manufactures and services in globalizing lands. Eckert IV projections. (Color figure available online.)

Perspective	Macro-Region	Croplands: Appropriated	Croplands: Use Footprint	Croplands: …hectares per capita	Croplands: Net Exported	Croplands: Imported	Croplands: Exported	Pasturelands: Appropriated	Pasturelands: Use Footprint	Pasturelands: …hectares per capita	Pasturelands: Net Exported	Pasturelands: Imported	Pasturelands: Exported
Consumption	Greater China	1400	1230	0.1	170	300	470	2770	1840	0.1	930	360	1290
Consumption	East Asia, not China	90	450	0.2	-360	370	10	320	860	0.4	-540	670	130
Consumption	Western Europe	810	1660	0.4	-850	970	120	450	1710	0.4	-1260	1310	50
Consumption	SE Asia and Oceania	1560	1260	0.2	290	160	450	2720	1670	0.3	1050	160	1210
Consumption	Russia and E. Europe	2180	2000	0.6	180	230	410	1110	1430	0.4	-330	400	70
Consumption	SW & Central Asia	850	800	0.3	40	130	170	3310	3030	1.2	280	80	360
Consumption	Africa	2410	2340	0.2	70	260	330	7880	7240	0.8	650	170	820
Consumption	Latin America	1770	1310	0.2	450	220	670	5100	4580	0.8	530	200	730
Consumption	South Asia	2100	2020	0.1	80	180	260	200	310	0.0	-110	120	10
Consumption	U.S. and Canada	2050	1940	0.6	110	560	670	2500	3400	1.0	-900	1080	170
Consumption	Middle East	160	340	0.3	-180	210	30	310	610	0.5	-290	340	50
Capital Investment	Greater China	1400	1520	0.1	-120	780	660	2770	2570	0.2	200	1440	1640
Capital Investment	East Asia, not China	90	830	0.4	-750	790	40	320	1590	0.8	-1280	1430	150
Capital Investment	Western Europe	810	2970	0.8	-2160	2450	290	450	4460	1.1	-4010	4170	160
Capital Investment	SE Asia and Oceania	1560	850	0.1	710	330	1040	2720	1570	0.3	1150	540	1690
Capital Investment	Russia and E. Europe	2180	1450	0.4	730	500	1230	1110	1550	0.5	-450	1020	570
Capital Investment	SW & Central Asia	850	600	0.2	250	250	500	3310	1780	0.7	1530	300	1830
Capital Investment	Africa	2410	1090	0.1	1310	280	1590	7880	3410	0.4	4470	300	4770
Capital Investment	Latin America	1770	1090	0.2	680	420	1100	5100	3320	0.6	1790	600	2380
Capital Investment	South Asia	2100	1620	0.1	480	370	850	200	690	0.0	-500	570	80
Capital Investment	U.S. and Canada	2050	3040	0.9	-1000	1890	890	2500	5190	1.6	-2690	3410	720
Capital Investment	Middle East	160	300	0.2	-140	270	130	310	530	0.4	-220	450	230
Final Demand	Greater China	1400	1370	0.1	30	290	320	2770	1930	0.1	840	270	1100
Final Demand	East Asia, not China	90	390	0.2	-300	320	10	320	830	0.4	-510	580	70
Final Demand	Western Europe	810	1530	0.4	-720	810	90	450	1370	0.3	-920	960	40
Final Demand	SE Asia and Oceania	1560	1280	0.2	280	130	410	2720	1700	0.3	1010	110	1120
Final Demand	Russia and E. Europe	2180	2040	0.6	140	200	340	1110	1360	0.4	-260	300	40
Final Demand	SW & Central Asia	850	830	0.3	20	120	130	3310	3260	1.3	50	60	110
Final Demand	Africa	2410	2350	0.2	50	250	310	7880	7450	0.8	430	140	580
Final Demand	Latin America	1770	1310	0.2	460	190	640	5100	4660	0.8	440	140	580
Final Demand	South Asia	2100	2050	0.1	50	160	210	200	280	0.0	-80	80	10
Final Demand	U.S. and Canada	2050	1850	0.6	190	460	650	2500	3190	1.0	-690	830	140
Final Demand	Middle East	160	350	0.3	-190	210	20	310	630	0.5	-310	340	30

Perspective	Macro-Region	Forestlands: Appropriated	Forestlands: Use Footprint	Forestlands: …hectares per capita	Forestlands: Net Exported	Forestlands: Imported	Forestlands: Exported	Total: Appropriated	Total: …hectares per capita	Total: Use Footprint	Total: …hectares per capita	Total: Net Exported	Total: Imported	Total: Exported
Consumption	Greater China	1440	1480	0.1	-40	850	810	5610	0.4	4550	0.3	1060	1510	2570
Consumption	East Asia, not China	360	1040	0.5	-680	790	110	770	0.4	2340	1.2	-1580	1830	260
Consumption	Western Europe	1420	3030	0.8	-1620	1990	370	2680	0.7	6410	1.6	-3730	4260	540
Consumption	SE Asia and Oceania	1410	760	0.1	650	250	900	5680	0.9	3690	0.6	1990	570	2560
Consumption	Russia and E. Europe	3380	1810	0.5	1570	300	1870	6670	2.0	5250	1.6	1420	930	2350
Consumption	SW & Central Asia	230	430	0.2	-190	260	60	4390	1.8	4260	1.7	130	470	600
Consumption	Africa	1870	1190	0.1	670	190	860	12160	1.3	10770	1.1	1390	620	2010
Consumption	Latin America	3150	2440	0.4	710	280	990	10020	1.8	8330	1.5	1690	700	2390
Consumption	South Asia	260	520	0.0	-270	310	40	2550	0.2	2850	0.2	-300	610	310
Consumption	U.S. and Canada	3320	3930	1.2	-610	1400	790	7860	2.4	9270	2.8	-1410	3040	1630
Consumption	Middle East	0	190	0.1	-190	190	0	480	0.4	1140	0.9	-660	740	80
Capital Investment	Greater China	1440	1770	0.1	-330	1060	730	5610	0.4	5860	0.4	-250	3280	3030
Capital Investment	East Asia, not China	360	1050	0.5	-690	840	150	770	0.4	3480	1.7	-2710	3060	350
Capital Investment	Western Europe	1420	3190	0.8	-1770	2250	480	2680	0.7	10620	2.7	-7940	8870	930
Capital Investment	SE Asia and Oceania	1410	720	0.1	690	280	970	5680	0.9	3140	0.5	2550	1150	3700
Capital Investment	Russia and E. Europe	3380	1670	0.5	1710	370	2090	6670	2.0	4670	1.4	2000	1890	3890
Capital Investment	SW & Central Asia	230	380	0.2	-150	260	110	4390	1.8	2760	1.1	1630	810	2440
Capital Investment	Africa	1870	810	0.1	1050	210	1270	12160	1.3	5320	0.6	6840	790	7630
Capital Investment	Latin America	3150	2020	0.4	1130	320	1440	10020	1.8	6420	1.1	3590	1340	4930
Capital Investment	South Asia	260	540	0.0	-280	370	90	2550	0.2	2850	0.2	-300	1310	1020
Capital Investment	U.S. and Canada	3320	4470	1.3	-1150	1900	740	7860	2.4	12700	3.8	-4840	7200	2360
Capital Investment	Middle East	0	220	0.2	-210	220	0	480	0.4	1050	0.8	-570	940	360
Final Demand	Greater China	1440	1690	0.1	-250	810	570	5610	0.4	4990	0.4	620	1370	1990
Final Demand	East Asia, not China	360	870	0.4	-510	580	70	770	0.4	2090	1.0	-1320	1470	150
Final Demand	Western Europe	1420	2560	0.6	-1150	1400	250	2680	0.7	5470	1.4	-2790	3170	380
Final Demand	SE Asia and Oceania	1410	780	0.1	630	130	770	5680	0.9	3760	0.6	1920	380	2300
Final Demand	Russia and E. Europe	3380	2010	0.6	1370	180	1550	6670	2.0	5420	1.6	1250	670	1930
Final Demand	SW & Central Asia	230	400	0.2	-170	210	40	4390	1.8	4490	1.8	-110	390	280
Final Demand	Africa	1870	1340	0.1	530	130	660	12160	1.3	11150	1.2	1010	530	1540
Final Demand	Latin America	3150	2510	0.4	640	130	770	10020	1.8	8480	1.5	1530	460	1990
Final Demand	South Asia	260	500	0.0	-250	270	20	2550	0.2	2830	0.2	-280	510	240
Final Demand	U.S. and Canada	3320	4020	1.2	-700	1050	350	7860	2.4	9060	2.7	-1200	2330	1140
Final Demand	Middle East	0	150	0.1	-150	150	0	480	0.4	1130	0.9	-650	700	50

Units: Except for columns indicating values expressed in hectares per capita, all values are in thousands of square km, rounded to the nearest ten.

Figure 5. Relationships of the appropriation of land uses, consumption, capital investment, and trade for various combinations of global macroregions, land use types, and modeling perspectives in 2007.

consumption, 32 percent is globalized from our revised consumption perspective, and 59 percent is globalized from our investment perspective. Footprint quantification is thus consequentially theory laden, no longer a single number to be converged on, whether considering the footprints of countries or of individual commodities.

In a relational quantitative sense, environment has become a profoundly more-than-local concept. From the investment perspective, the median square meter of land use in the world goes to support futures in another country, not to support local populations. Across the lenses taken and the land uses considered here, the percentages of land considered globalized beyond the eleven macroregions are almost up to the levels of percentages of land globalized in the 134 base regions. This indicates that the relational mappings in Figures 1 and 2, although aggregated, capture most of the interrelations that stretch beyond the borders of national territories. Especially from one perspective here, global trade and divisions of labor have led to a dominance of socioecological relationships linking land and demand that are effectively intercontinental in scale, no longer within single countries nor even merely crossing the borders of neighboring territories. Using our relational quantitative approach, everything does relate to everything else but, contrary to the commonsense expressed by Tobler's first law of geography, in neoliberal globalization, many things near in absolute space are less related to each other than they are related to things on separate continents.

Aggregating nearby individuals into populations and physically proximate lands into areas have been central conceptual tools of statecraft (and, relatedly, of much academic research; Foucault 2009). The uneven spatial distributions that result, especially of the ratios of population to settled bioproductive lands, form many commonplace understandings of world human–environmental geography and of differential potentials for "development." Figure 5 roughly echoes this absolute spatial imaginary in its column indicating the direct land appropriations in hectares per capita, which range from 0.2 in South Asia up to 2.4 in the United States and Canada. Given the complexity of global economies today, to what extent are these numbers and patterns reflective of the hectares of land use embodied within per capita demand?

The final demand perspective on per capita land usage suggests that in hectares per capita, those in

Western Europe might only appropriate 0.7, but they use 1.4 through their final demand—a substantial offshoring of footprint (Figure 5). That lens, however, implies that many of the land-rich regions of the Global South described earlier not only appropriate the production of considerable land area per capita but that similar amounts end up in local per capita land footprints: Those in Africa appropriate 1.3 and consume 1.2 and those in Latin America appropriate 1.8 but still consume 1.5. From our revised consumption perspective, African per capita land use barely falls, with a small net subsidy to others, to 1.1, and that in Latin America remains roughly constant, although Western Europe and the United States and Canada show slight rises to 1.6 and 2.8, respectively. The final demand perspective used in past consumption research suggests (and from these metrics, at least, our consumption perspective largely agrees) that lands are not only mostly used close to where they are harvested (recall Table 1) but, more important, the global exchange in the ecological benefits from land we have just described is surprisingly in balance. If so, the spatial distribution of ecological benefits at the broadest scales is somewhat congruent with biocapacities, populations, and their per capita ratios—and, especially in neo-Malthusian writings, observers can make much of the resulting distribution of relative abundance and scarcity.

Viewing per capita variations in land use from the perspective of capital investment, however, a type of footprint for capital not consumption, local population and land endowments appear to recede in importance relative to positionality within structures of the contemporary international division of labor and the capitalist world ecology. South Asia and China still only use 0.2 and 0.4, respectively, whereas Africa now only uses 0.6 hectares per person, Southeast Asia and Oceania use 0.5, and Latin America uses 1.1. By contrast, Western Europe uses 2.7 and the United States and Canada use the products of 3.8 hectares per capita while investing in their economic futures. In other words, the United States and Canada receive the benefit of 1.6 hectares for every 1 hectare it appropriates locally; Western Europe likewise receives 4 hectares for each of its own; and East Asia outside of China receives 4.5. At the same time, even after accounting for its trade, including its net food imports (Rakotoarisoa, Iafrate, and Paschali 2011), Africa receives benefits of only 0.4 hectares for each hectare it harvests; Latin America, southwest and central Asia, Southeast Asia, and Oceania receive 0.6; and China and South Asia each receive the use of approximately 1 hectare for 1 hectare appropriated, albeit at the lowest per capita levels. Received understandings of roles played by relative land scarcities and lifestyle differences could still be read from the sequencing of these lists. It also now appears, though, that topologies and power geometries of an unevenly globalizing capitalist world ecology play a powerful role in the global redistribution of ecological benefits per capita, offering a quantitative and cartographic approach to land and population that supports the sense common in geographic scholarship today of caution toward, or even rejection of, neo-Malthusianism.

Taking these explorations of globalization and land down to fine scale rooted in the tracts of land formed by a global grid yields another set of complementary insights. In the maps of Figure 3—the first comprehensive explorations of the globalization of land from commodity relations at a subnational scale—certain landscapes are significantly more globalized from a capital investment lens than from a consumption lens. These two perspectives offer particularly different perspectives for the roles of lands in large belts of sub-Saharan Africa, of central Asia, and many parts of Latin America. Some lands are more likely to support economic activity domestically than abroad compared to many other regions, regardless of land type and perspective, as with many lands of the United States and South Asia. Other lands, such as much of Canada and Southeastern Asia, tend to be highly globalized from both capital investment and consumption perspectives.

Yet similarities across these maps of globalization might mask other differences in global role and, equally, lands of parallel positionality might appear to have different degrees of globalization. In Figure 3, croplands between the Iberian Peninsula and the Ural Mountains all undergo a shift from local toward global with the shifting of perspective from consumption to capital investment. Figures 2 and 5, however, make it clear that the lands of Western Europe, although perhaps "globalized" beyond national borders, end up contributing to capital investment within neighboring countries of Western Europe, whereas the land footprints from Eastern Europe and Russia are mostly exported out of the region—and, largely, to Western Europe.

Indeed, the interrelations in Figures 1 and 2 are complicated, but we note a few generalizations across theoretical lenses. Many flows originate in the lands of the Global South and contribute to demand in the Global North, yet patterns also indicate territories of an intermediate role, in a complex hierarchy beyond periphery and core. Figures 2 and 5 show that there are regions that tend to be net suppliers of land (Africa, Latin America, Southeast Asia), regions that both supply and externalize demands for land (South Asia, Russia and Eastern Europe, China, and, in certain cases, the United States and Canada), and regions that tend to strongly depend on others without much

Land type	Model	Macro-Region	A1 Appropriated	A2 and consumed as agri. goods	A3 and consumed as manuf. or services	A4 % consumed as manuf. or services	C1 Consumed	C2 ...through agri. goods	C3 ...through manuf. or services	C4 % through manuf. or services	NE Net Exported	I1 Imported	I2 ...through agri. goods	I3 ...through manuf. or services	I4 ...% through manuf. or services	E1 Exported	E2 and consumed as agri. goods	E3 and consumed as manuf. or services	E4 % consumed as manuf. or services
Croplands	Consumption Model	Greater China	1400	830	570	41	1230	820	410	33	170	300	210	100	32	470	220	260	54
		East Asia, not China	90	60	20	26	450	280	170	37	-360	370	220	150	40	10	10	10	54
		Western Europe	810	560	250	31	1660	1100	570	34	-850	970	610	360	37	120	70	40	37
		SE Asia and Oceania	1560	1250	310	20	1260	1040	220	18	290	160	100	50	34	450	310	140	31
		Russia and Eastern Europe	2180	1820	360	17	2000	1710	300	15	180	230	170	60	28	410	280	130	32
		SW & Central Asia	850	750	100	12	800	730	70	9	40	130	110	20	18	170	120	50	30
		Africa	2410	2270	140	6	2340	2260	80	3	70	260	230	30	13	330	240	90	27
		Latin America	1770	1420	340	19	1310	1090	220	17	450	220	170	50	24	670	500	170	26
		South Asia	2100	1840	260	12	2020	1830	190	9	80	180	150	20	13	260	160	90	36
		U.S. and Canada	2050	1480	560	27	1940	1270	660	34	110	560	320	250	44	670	530	140	21
		Middle East	160	140	20	10	340	290	50	14	-180	210	170	40	20	30	20	10	40
	Final Demand Model	Greater China	1400	700	700	50	1370	730	630	46	30	290	180	110	38	320	150	170	54
		East Asia, not China	90	60	20	26	390	260	130	33	-300	320	200	110	36	10	0	10	53
		Western Europe	810	540	270	34	1530	1020	510	33	-720	810	550	270	33	90	60	30	34
		SE Asia and Oceania	1560	1220	330	21	1280	1030	250	19	280	130	90	40	32	410	290	130	31
		Russia and Eastern Europe	2180	1780	400	18	2040	1680	360	18	140	200	150	50	27	340	250	90	27
		SW & Central Asia	850	780	70	8	830	780	60	7	20	120	100	20	16	130	100	30	21
		Africa	2410	2250	150	6	2350	2240	110	5	50	250	210	40	15	310	230	80	26
		Latin America	1770	1420	340	19	1310	1110	200	16	460	190	150	30	18	640	470	170	27
		South Asia	2100	1800	290	14	2050	1800	250	12	50	160	140	20	13	210	140	70	31
		U.S. and Canada	2050	1450	590	29	1850	1220	640	34	190	460	280	180	39	650	510	140	21
		Middle East	160	150	20	10	350	300	50	13	-190	210	170	40	18	20	10	10	36
Pasturelands	Consumption Model	Greater China	2770	1780	990	36	1840	1250	590	32	930	360	210	150	41	1290	740	540	42
		East Asia, not China	320	210	110	34	860	470	390	45	-540	670	330	340	51	130	70	60	48
		Western Europe	450	330	110	26	1710	1060	650	38	-1260	1310	750	560	43	50	30	20	42
		SE Asia and Oceania	2720	1700	1010	37	1670	1020	640	39	1050	160	80	80	49	1210	760	440	37
		Russia and Eastern Europe	1110	980	130	11	1430	1220	210	15	-330	400	280	120	31	70	40	40	52
		SW & Central Asia	3310	2920	390	12	3030	2810	220	7	280	80	50	30	36	360	160	200	56
		Africa	7880	7170	710	9	7240	6840	400	5	650	170	130	40	21	820	470	350	43
		Latin America	5100	4210	900	18	4580	3820	760	17	530	200	130	70	37	730	510	220	30
		South Asia	200	190	10	3	310	270	40	13	-110	120	80	40	31	10	0	0	31
		U.S. and Canada	2500	1810	690	28	3400	2300	1100	32	-900	1080	600	480	44	170	110	60	37
		Middle East	310	270	50	14	610	510	90	15	-290	340	270	70	21	50	20	30	53
	Final Demand Model	Greater China	2770	1610	1160	42	1930	1110	830	43	840	270	150	120	45	1100	650	450	41
		East Asia, not China	320	290	30	9	830	530	290	36	-510	580	290	280	49	70	50	20	29
		Western Europe	450	330	120	26	1370	940	440	32	-920	960	630	330	35	40	20	10	38
		SE Asia and Oceania	2720	1780	940	35	1700	1120	580	34	1010	110	60	50	46	1120	720	400	36
		Russia and Eastern Europe	1110	990	120	11	1360	1190	180	13	-260	300	220	70	24	40	20	20	43
		SW & Central Asia	3310	3140	160	5	3260	3120	140	4	50	60	40	20	36	110	70	40	40
		Africa	7880	7110	780	10	7450	6850	600	8	430	140	110	30	24	580	360	210	37
		Latin America	5100	4510	600	12	4660	4170	500	11	440	140	100	40	28	580	440	140	24
		South Asia	200	190	10	3	280	240	30	11	-80	80	60	30	32	10	0	0	24
		U.S. and Canada	2500	1780	710	29	3190	2200	990	31	-690	830	510	320	39	140	100	40	31
		Middle East	310	280	40	11	630	540	80	13	-310	340	280	60	18	30	10	10	49
Forests	Consumption Model	Greater China	1440	590	850	59	1480	660	820	55	-40	850	360	480	57	810	290	520	64
		East Asia, not China	360	150	210	58	1040	320	720	69	-680	790	200	590	75	110	30	80	73
		Western Europe	1420	540	880	62	3030	1040	1990	66	-1620	1990	640	1350	68	370	130	240	64
		SE Asia and Oceania	1410	660	750	53	760	360	400	53	650	250	80	170	67	900	390	510	57
		Russia and Eastern Europe	3380	1420	1970	58	1810	850	960	53	1570	300	120	180	59	1870	690	1180	63
		SW & Central Asia	230	140	90	39	430	270	160	37	-190	260	150	110	43	60	20	40	65
		Africa	1870	1270	600	32	1190	1010	190	15	670	190	110	80	43	860	370	490	57
		Latin America	3150	1650	1500	48	2440	1360	1080	44	710	280	110	170	61	990	400	590	59
		South Asia	260	200	60	23	520	410	120	22	-270	310	230	90	28	40	20	30	64
		U.S. and Canada	3320	1480	1840	56	3930	1740	2190	56	-610	1400	520	880	63	790	250	530	68
		Middle East	0	0	0	22	190	80	120	60	-190	190	80	120	60	0	0	0	58
	Final Demand Model	Greater China	1440	470	980	68	1690	530	1160	69	-250	810	250	570	70	570	180	390	68
		East Asia, not China	360	130	230	63	870	220	650	75	-510	580	100	480	83	70	10	60	80
		Western Europe	1420	460	960	68	2560	750	1810	71	-1150	1400	370	1030	73	250	70	180	71
		SE Asia and Oceania	1410	540	870	61	780	280	490	63	630	130	30	100	75	770	290	470	62
		Russia and Eastern Europe	3380	1120	2260	67	2010	720	1290	64	1370	180	60	120	69	1550	460	1090	70
		SW & Central Asia	230	130	100	45	400	220	180	45	-170	210	110	100	49	40	10	30	72
		Africa	1870	1160	710	38	1340	970	370	28	530	130	50	90	64	660	240	420	64
		Latin America	3150	1580	1560	50	2510	1320	1190	47	640	130	50	80	64	770	310	460	60
		South Asia	260	180	80	31	500	340	170	33	-250	270	170	100	38	20	10	10	70
		U.S. and Canada	3320	1710	1610	49	4020	2080	1940	48	-700	1050	460	590	57	350	90	260	75
		Middle East	0	0	0	26	150	50	100	69	-150	150	50	100	69	0	0	0	63

Units: Except for percentages, all numbers are in thousand square km, rounded to the nearest ten.

Figure 6. Relative roles of agricultural goods versus manufactures and services in globalizing lands.

(agricultural land-based) reciprocity (Western Europe and East Asia outside of China). Net flows tend to originate in regions earlier in this list and contribute to those later, not only across these three categories but within them as well.

Other patterns of relations and magnitudes do vary depending on the modeling perspective and land type of interest. The mixed role of the United States and Canada as both importers and exporters of embodied croplands as seen from the final demand perspective gives way to the image of a strong net importer when lands are viewed from the perspective of capital investment. From different lenses, Africa, Greater China, and Southeast Asia and Australia are each rich sources of pasturelands embodied in international trade. Yet the relative contributions of African pasturelands abroad become dominant among exporting regions when viewing lands in terms of capital investment. Indeed, the capital investment perspective shows greater polarization than other perspectives among the interregional relationships as well as the greater relative dominance of both the United States and Canada and Western Europe as the net beneficiaries of global land use. From this perspective, the large relative net contributions to the Global North of not only Africa but also Latin America become particularly clear.

Greater China is a region in which land and economy play complicated global roles. In the case of combustion carbon emissions, and especially from the perspective of capital investment, China is a tremendous (and rather unrequited) provider of offshored emissions for demand in the Global North (Bergmann 2013). The case of land use is considerably less straightforward, however. Figure 5 indicates that China is indeed a large supplier of embodied land use to the rest of the world—the largest among the macroregions, in fact, in the consumption model. Given that China begins from such low levels of land appropriated per person, however, and generally has similar levels in consumption per capita because of trade, demand in the region is a substantial recipient of land, often croplands and forestlands, harvested elsewhere, as seen in Figures 1 and 2. Whether China is a net supplier or recipient of land use embodied in trade depends on the perspective. Further, in Figure 4, the degree to which many of China's globalized lands reach demand in other regions in the form of manufacturing and services, not agricultural goods, is striking. With respect to croplands and pastures, whether as producer or consumer, importer or exporter, China has among the highest if not the highest percentage of its globalized lands that reach consumers abroad in the form of manufactures and services instead of in the form of agricultural products.

When land footprints are traded across borders, they are more likely than those lands traded domestically to be encountered by consumers in the form of manufactured goods and services; in Figure 6, the values of column A4 (the percentage of appropriated lands eventually consumed as manufactures or services) tend to be less than those of E4 (the percentage of exported lands that are eventually consumed through manufactures or services) in croplands, in forests, and especially in pastures. Different types of land are not globalized by manufactures and services to the same extents, however. In both Figure 4 and Figure 6, forested land is more likely to be consumed as manufactured goods and services than are crop or pasture lands. Research and classroom activities that ponder our commodity connections to distant farmlands and forests might, in the future, consider electronics or health care alongside papayas and furniture.

Conclusions

Despite critiques offered by geographers, political ecologists, and others, many observers still understand, calculate, and visualize human–environment relations using an implicit absolute spatiality. Spatial juxtapositions of populations and landscapes might suggest that understandings of socionatural outcomes should similarly depend on localized metrics. Mappings of local resources per capita are commonplace. Standard computational and cartographic frameworks facilitate such approaches.

By contrast, we offer computational methods envisioning lands through their connections, whether proximate or distant according to absolute space. We examine the positionalities of lands as spaces (re)produced within the processes of the capitalist world ecology. Our relational quantitative and cartographic arguments demonstrate that local environments and population densities are hardly destiny, for better and for worse, when it comes to who reaps which benefits from what lands in an era of globalization. The empirics we present here are also both more comprehensive in the indirect connections they trace and more spatially disaggregated than previous research. Studies of individual commodity chains or regions under globalization can be consonant with our results, although in a world where everything is (unevenly) interconnected, massive relational quantitative approaches differentiate themselves by the type of evidence they are capable of offering about the contours of the overall net interrelations among people and land. Our work analyzes and visualizes ways in which an ongoing global net redistribution and polarization of agroecological benefits, especially from Global South to Global North, is characteristic, even constitutive, of the contemporary capitalist world ecology. If so, commentators on human–environment relations might wish to spend less time considering "population pressure" and more time investigating forms of "capital pressure."

Environment itself as a concept has only recently emerged as primarily biophysical, as often spoken in the singular with a definite article, and as often global in scale instead of narrowly considered in relation to a particular object of more modest being (Taylor and Buttel 1992; Proctor 2009). Yet as suggested by Law (2004), "the global" need not be a realm of concepts whose existence is at broad scales. Indeed, here, we explore landscapes as neither local nor uniformly and singularly global but as equally understood in terms of the connections in which they participate. Inspired by Law, we peer down into how socioecological relationships enfold fields, forests, fixed capital accumulation, and populations around the world—a quantitative homage to Leibnizian monadology (Deleuze 1993; Latour et al. 2012; Leibniz 2012; Tarde 2012). We locate anthropogenic landscapes with existences that are not primarily of the local but are at least equally of elsewhere—and we show that from certain lenses, these nonlocal landscapes are the norm.

We offer several perspectives on the globalization of land and its relationships with populations, near and far. Each has its theoretical standpoint, emphases, and elisions. The footprints of individual commodities cannot be resolved into single numbers, as we so often assume within our classrooms and public life, without reference to theoretical standpoint. This is not a matter of different models making different assumptions and suffering from uncertainty in pursuit of quantifying a singular concept. Especially as the relational perspectives we offer on lands, commodities, and benefits to capital and consumers are joined by other perspectives not considered here—such as those examining aesthetic, medical, cultural, or ecological relations—a nuanced (more-than-) quantitative pluralism would be a great asset to working through the complexities of knowledge claims (Barnes and Sheppard 2010; Bergmann 2013). Policy relevance might be less a matter of conforming to a technocratic process enshrining the singular answers of experts grappling with uncertainty and more a matter of contributing to an agonistic pluralism and a fuller democratic debate as to the meaning and significance of different perspectives on lands and our complex interrelations to them.

Seen from a lens of capital, the median square meter of land use in the world contributes to the future of human populations that are outside of the country of that land—a degree of globalization unimagined by previous research, with significant consequences for how we understand the spatiality of our relationships to landscape. As we make an Anthropocene, if surely not entirely as we please; as we internalize, externalize, narrate, and know, what roles will we allow for spaces that are not absolute? When we gaze into a landscape, when we peer into a product, will we be more likely to see details unfolding or worlds enfolding?

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Notes

1. We derived this figure from 2007 FAO (2015) data using the ratio of the sum of the export values of wheat, rice, barley, maize, rye, oats, millet, sorghum, buckwheat, triticale, canary seed, and mixed grain over the sum of the gross production values of the same commodities. Note that the category of rice differs slightly between export and production figures. Excluding rice from the measure of export intensity changes the figure we offer from 14 to 17 percent.
2. Using 2009 FAO data (2011, A–3), we calculated ratios of production summed across the described categories over sums of production figures for the same. Timber figures are measured by volume, whereas pulp and paper figures are by weight.

3. We obtained this result by subtracting import value from export value of total agriculture products using 2007 FAO (2015) data. Africa had a deficit in overall agricultural trade of $22 billion.
4. Several research teams have recently devoted considerable efforts to comparing the extent to which the results of footprint analyses depend on the choice of underlying database (Inomata and Owen 2014). The results have suggested why certain discrepancies exist, finding overall that there is strong numerical agreement among footprint analyses conducted. This article uses the most commonly employed database.

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Appendix A: Regions and Agroecological Zones

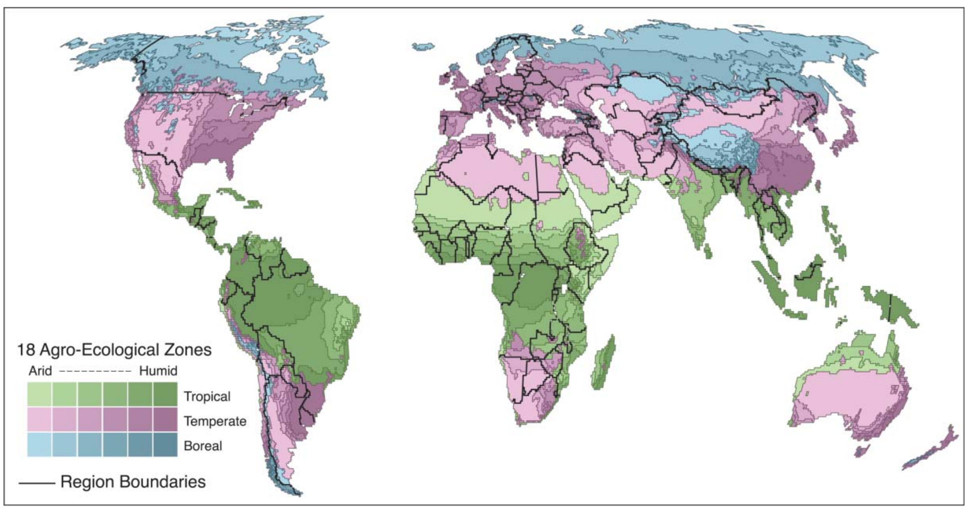

Figure A1. One hundred thirty-four regions subdivided by eighteen agroecological zones. The global interregional socioecological accounting matrices developed here not only subdivided territory at a nation-state scale but, within each such region, differentiated how sectors drew their inputs from forests, pastures, and croplands of different agroecological zones. (Color figure available online.)

Appendix B: Classification of Economic Sectors into Aggregate Categories

Most calculations are at the maximum level of detail and disaggregation possible—in regions, economic sectors, AEZs, and land uses. For certain analyses, we aggregated the outcomes into fewer classes of ecological–economic activity or into fewer macroregions. Here, we describe GTAP sectors and their aggregation (Figure B1).

	GTAP Sector #	GTAP Sector Name	Description
Agricultural and other primary commodities, raw and processed	1	pdr	Paddy Rice: rice, husked & unhusked
	2	wht	Wheat: wheat & meslin
	3	gro	Other Grains: maize (corn), barley, rye, oats, other cereals
	4	v_f	Veg & Fruit: vegetables, fruit, nuts, potatoes, cassava, truffles
	5	osd	Oil Seeds: oil seeds & oleaginous fruit; soy beans, copra
	6	c_b	Cane & Beet: sugar cane & sugar beet
	7	pfb	Plant Fibres: cotton, flax, hemp, sisal & other raw vegetable materials used in textiles
	8	ocr	Other Crops: live plants; cut flowers & buds; flower & fruit seeds; vegetable seeds, beverage & spice crops, unmanufactured tobacco, cereal straw & husks, unprepared, whether or not chopped, ground, pressed or in the form of pellets; swedes, mangolds, fodder roots, hay, lucerne (alfalfa), clover, sainfoin, forage kale, lupines, vetches & similar forage products, whether or not in the form of pellets, plants & parts of plants used primarily in perfumery, in pharmacy, or for insecticidal, fungicidal or similar purposes, sugar beet seed & seeds of forage plants, other raw vegetable materials
	9	ctl	Cattle: cattle, sheep, goats, horses, asses, mules, & hinnies; & semen thereof
	10	oap	Other Animal Products: swine, poultry & other live animals; eggs, in shell (fresh or cooked), natural honey, snails (fresh or preserved) except sea snails; frogs' legs, edible animal prods. n.e.c., hides, skins & furskins, raw, insect waxes & spermaceti
	11	rmk	Raw milk
	12	wol	Wool: wool, silk, & other raw animal materials used in textiles
	13	frs	Forestry: forestry, logging & related service activities
	14	fsh	Fishing: hunt., trap. & game propagation incl. serv. activit., fishing, fish farms; serv. activ. incidental to fishing
	15	col	Coal: mining & agglomeration of hard coal, lignite & peat
	16	oil	Oil: extract. crude petrol. & nat. gas (part), serv. activ. incidental to oil & gas extract. exclud. surveying (part)
	17	gas	Gas: extract. crude petrol. & nat. gas (part), serv. activ. incidental to oil & gas extract. exclud. surveying (part)
	18	omn	Other Mining: mining of metal ores, uranium, gems. other mining & quarrying
	19	cmt	Cattle Meat: fresh or chilled meat & edible offal of cattle, sheep, goats, horses, asses, mules, & hinnies; raw fats or grease from any animal or bird.
	20	omt	Other Meat: pig meat & offal; preserves & preparations of meat, meat offal or blood, flours, meals & pellets of meat or inedible meat offal; greaves
	21	vol	Vegetable Oils: crude & refined oils of soya-bean, maize (corn), olive, sesame, ground-nut, olive, sunflower-seed, safflower, cotton-seed, rape, colza & canola, mustard, coconut palm, palm kernel, castor, tung jojoba, babassu & linseed, perhaps partly or wholly hydrogenated, inter-esterified, re-esterified or elaidinised. Also margarine & similar preparations, animal or vegetable waxes, fats & oils & their fractions, cotton linters, oil-cake & other solid residues resulting from the extraction of vegetable fats or oils; flours & meals of oil seeds or oleaginous fruits, except those of mustard; degras & other residues resulting from the treatment of fatty substances or animal or vegetable waxes
	22	mil	Milk: dairy products
	23	pcr	Processed Rice: rice, semi- or wholly milled
	24	sgr	Sugar
	25	ofd	Other Food: prepared & preserved fish or vegetables, fruit & vegetable juices, prepared & preserved fruit & nuts, all cereal flours, groats, meal & pellets of wheat, cereal groats, meal & pellets n.e.c., oth. cereal grain prods. (incl. corn flakes), oth. vegetable flours & meals, mixes & doughs for prep. of bakers' wares, starches & starch prods.; sugars & sugar syrups n.e.c., preps. used in animal feed., bakery prods., cocoa, chocolate & sugar confectionery, macaroni, noodles, couscous & similar farinaceous prods., food prods. n.e.c.
	26	b_t	Beverages & Tobacco products
	27	tex	Textiles: textiles & man-made fibers
	28	wap	Wearing Apparel: clothing, dressing & dyeing of fur
	29	lea	Leather: tanning & dressing of leather; luggage, handbags, saddlery, harness & footwear
	30	lum	Lumber: wood & products of wood & cork, exc. furniture; articles of straw & plaiting materials
	31	ppp	Paper & Paper Products: includes publishing, printing & reproduction of recorded media
	32	p_c	Petroleum & Coke: coke oven products, refined petroleum products, processing of nuclear fuel
	33	crp	Chemical Rubber Products: basic chemicals, other chemical products, rubber & plastics products
	34	nmm	Non-Metallic Minerals: cement, plaster, lime, gravel, concrete
	35	i_s	Iron & Steel: basic production & casting
	36	nfm	Non-Ferrous Metals: production & casting of copper, aluminium, zinc, lead, gold, & silver
	37	fmp	Fabricated Metal Products: Sheet metal products, but not machinery & equipment

Figure B1. Classification of economic sectors into aggregate categories.

	GTAP Sector #	Name	Description
Manufactured goods and services	38	mvh	Motor Motor vehicles & parts: cars, lorries, trailers & semi-trailers
	39	otn	Other Transport Equipment: Manufacture of other transport equipment
	40	ele	Electronic Equipment: office, accounting & computing machinery, radio, telev. & comm. equip. & apparatus
	41	ome	Other Machinery & Equipment: electrical machinery & apparatus n.e.c., medical, precision & optical instruments, watches & clocks
	42	omf	Other Manufacturing: includes recycling
	43	ely	Electricity: production, collection & distribution
	44	gdt	Gas Distribution: distribution of gaseous fuels through mains; steam & hot water supply
	45	wtr	Water: collection, purification & distribution
	46	cns	Construction: building houses factories offices & roads
	47	trd	Trade: all retail sales; wholesale trade & commission trade; hotels & restaurants; repairs of motor vehicles & personal & household goods; retail sale of automotive fuel
	48	otp	Other Transport: road, rail; pipelines, auxiliary transport activities; travel agencies
	49	wtp	Water transport
	50	atp	Air transport
	51	cmn	Communications: post & telecommunications
	52	ofi	Other Financial Intermediation: includes auxiliary activities but not insurance & pension funding (see next)
	53	isr	Insurance: includes pension funding, except compulsory social security
	54	obs	Other Business Services: real estate, renting & business activities
	55	ros	Recreation & Other Services: recreational, cultural & sporting activities, other service activities; private households with employed persons
	56	osg	Other Services (Government): public administration & defense; compulsory social security, education, health & social work, sewage & refuse disposal, sanitation & similar activities, activities of membership organizations n.e.c., extra-territorial organizations & bodies
	57	dwe	Dwellings: ownership of dwellings (imputed rents of houses occupied by owners)
	-	--	Other SAM sectors associated with region & households, as detailed in article text and Bergmann (2013)

Sector descriptions edited from source: https://www.gtap.agecon.purdue.edu/databases/contribute/detailedsector.asp

Figure B1. *(Continued)*

Appendix C: Macroregional Aggregations of Territory

For certain analyses and visualizations, we aggregate the 134 GTAP 8.1 regions into eleven macroregions. Relative similarities in ecological and economic relations, data constraints, and conventions lead to our choice of macroregions. Certain GTAP regions are already aggregates due to data constraints. These are listed by three-letter GTAP codes followed by parenthetical noting of the territories included. Finally, in Figures 1 and 2, arrows originate from, and point to, the spatial centroids of one territory, the name of which is listed in italics, within each macroregion.

Greater China: *China*, Hong Kong, and Taiwan.

Other East Asia: *Japan*, South Korea, Mongolia, and XEA (Macau and the Democratic People's Republic of Korea).

Western Europe: *Germany*, Belgium, France, Finland, Austria, Switzerland, Denmark, Spain, United Kingdom, Ireland, Italy, Luxembourg, Malta, The Netherlands, Norway, Portugal, Sweden, and XEF (Iceland and Liechtenstein).

Southeast Asia and Oceania: *Indonesia*, Vietnam, Australia, Cambodia, Laos, Malaysia, New Zealand, Philippines, Singapore, Thailand, XOC (American Samoa, Cook Islands, Fiji, Micronesia, Guam, Kiribati, Marshall Islands, Northern Mariana Islands, New Caledonia, Niue, Nauru, Pitcairn, Palau, Papua New Guinea, French Polynesia, Solomon Islands, Tokelau, Tonga, Tuvalu, United States Minor Outlying Islands, Vanuatu, Wallis and Futuna, and Samoa), XTW (Antarctica, French Southern Territories, Bouvet Island, and British Indian Ocean Territory), and XSE (Brunei Darussalam, Myanmar, and Timor-Leste).

Eastern Europe and Russia: *Russia*, Poland, Albania, Bulgaria, Belarus, Cyprus, Czech Republic, Estonia, Greece, Croatia, Hungary, Lithuania, Latvia, XEE (Moldova), Romania, Slovakia, Slovenia, Ukraine, and XER (Andorra, Bosnia and Herzegovina, Faroe Islands, Guernsey, Gibraltar, Isle of Man, Jersey, Monaco, Macedonia, Montenegro, San Marino, Serbia, and the Vatican City State).

Southwest and Central Asia: Armenia, Azerbaijan, Georgia, Iran, Kazakhstan, Kyrgyzstan, Turkey, XSU (Tajikistan, Turkmenistan, and *Uzbekistan*), and XSA (Afghanistan, Bhutan, and Maldives).

Africa: Benin, Burkina Faso, Botswana, Cameroon, Côte d'Ivoire, Egypt, Ethiopia, Ghana, Guinea, Kenya, Morocco, Madagascar, Mozambique, Mauritius, Malawi, Namibia, Nigeria, Rwanda, Senegal, Tanzania, Uganda, South Africa, Zambia, Zimbabwe, Togo, Tunisia, XAC (Angola and *The Democratic Republic of the Congo*), XEC (Burundi, Comoros, Djibouti, Eritrea, Mayotte, Sudan, Somalia, and Seychelles), XCF (Central African Republic, Congo, Gabon, Equatorial Guinea, Sao Tome and Principe, and Chad), XWF (Cape Verde, Gambia, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Saint Helena, and Sierra Leone), XNF (Algeria, Western Sahara, Libya), and XSC (Lesotho and Swaziland).

Latin America: *Brazil*, XCA (Belize), Argentina, Bolivia, Chile, Colombia, Costa Rica, Ecuador, Mexico, Guatemala, Honduras, Nicaragua, Panama, Peru, Paraguay, El Salvador, Uruguay, Venezuela, XCB (Aruba, Anguilla, Netherlands Antilles, Antigua & Barbuda, Bahamas, Barbados, Cuba, Cayman Islands, Dominica, Dominican Republic, Grenada, Haiti, Jamaica, Saint Kitts and Nevis, Saint Lucia, Montserrat, Puerto Rico, Turks and Caicos, Trinidad and Tobago, Saint Vincent and the Grenadines, British Virgin Islands, and the U.S. Virgin Islands), and XSM (Falkland Islands, French Guiana, Guyana, South Georgia, and the South Sandwich Islands, and Suriname).

South Asia: *India*, Bangladesh, Nepal, Pakistan, and Sri Lanka.

United States and Canada: *United States*, Canada, and XNA (Bermuda, Greenland, and Saint Pierre, and Miquelon).

Middle East: *Saudi Arabia*, United Arab Emirates, Bahrain, Israel, Kuwait, Oman, Qatar, and XWS (Iraq, Jordan, Lebanon, Palestinian Territories, Syria, and Yemen).