Abstract

Land use change and leakage effects stemming from technological change, conservation programs, and other policy interventions have received considerable attention in the scientific literature in the past decade. Economists have offered important insights about these linkages, yet much of the analysis undertaken by the land change science community does not fully avail itself of these insights. Similarly, many of the economic contributions to this field have ignored important findings from the land change science community. This paper, written by an economist, seeks to better communicate to members of the land change science community the key economic mechanisms behind land use, leakage and spillovers and how they might contribute to shaping future analyses. It does so using a series of successively more complex economic models, with each new model illustrating the importance of an added economic channel for land use change. The paper concludes by revisiting key insights which have emerged from research in the land change science community and their implications for economists conducting research into land use change.

Introduction and motivation

There is a rich literature on land use change and spillover effects related to technological change, conservation programs, biofuels, climate impacts as well as mitigation policies (Pfaff and Robalino 2017, Meyfroidt et al 2013, Villoria et al 2014, Hertel and Tyner 2013, Lambin and Meyfroidt 2011, Searchinger et al 2008). Economists have made important contributions along the way, starting with von Thunen (1842). Importantly for this paper, they have focused attention on the potential for land use leakage (Angelsen and Kaimowitz 2001, Gan and McCarl 2007). However, much of the analysis of land use change and spillover effects does not incorporate key insights from economics. Additionally, when viewed from the other side of the fence, many of the economic contributions to this field have ignored insights from the land change science community, including the importance of fine scale spatial resolution, the importance of behavioral heterogeneity, as well as the key role of local governance in determining patterns of land use change. Much of this knowledge gap stems from poor communication. As an economist undertaking interdisciplinary research on land use issues, I am often reminded by those outside our field of the inaccessible, jargon-heavy language which we typically use to convey our findings. The purpose of this paper is to contribute to building more effective bridges between the economics and land change science communities. In particular, it seeks to highlight, for the land use change community, the key economic mechanisms behind land use, leakage and spillovers. This is done through a series of successively more complex economic models (table 1), each based on prior work by myself and co-authors. Here, this stream of work is organized in a succession of increasing complexity, each time adding a new economic channel influencing land use change. In the concluding section I will turn to important insights which have emerged from research in the land change science community and their implications for economic research into land use change.

Insights from the unified global model: economic responses to scarcity blunt cropland expansion

In the spirit of starting with the simplest possible economic model of global land use, we begin with a unified global, agricultural economy (figure 1) in which we focus on the extent of cropland expansion...
in response to growth in the demand for agricultural commodities (e.g. due to growth in population, income and biofuels). In this context, it seems intuitive that, if demand were to increase by 10% due, e.g. to population growth, while farming techniques remain unaltered, then the world would need 10% more land—of equal average quality—to feed the additional people. However, over the period: 1961–2006, global population more than doubled, yet global cropland experienced net growth of just 12%, according to statistics from the United Nations Food and Agriculture Organization (FAO). A large part of this difference can be explained by the fact that agricultural technologies did not remain unchanged. Among other things, many parts of the world experienced a ‘Green Revolution’ during which crop yields were greatly increased through the introduction of new seed varieties and more intensive use of fertilizers and irrigation (Evenson and Gollin 2003). In addition, the intensity with which existing lands are cropped increased significantly through double- and even triple-cropping (Bruinsma 2009). So the net increase in cropland extent over this historical period is an indication that, in the global footrace between demand and supply, demand appears to have been dominant—although advances in technology have nearly kept pace with the growing, ever-richer global population.

Up to this point, the line of argument has abstracted from economic factors. For example, we have not considered the response of consumers and producers to changes in the scarcity of cropland—or of food for that matter. It turns out that these economic responses can be quite important in shaping the long run evolution of land use. In order to see how these economic forces interact with the biophysical factors discussed in the previous paragraph, consider figure 1, which introduces economic considerations into this discussion (parameters entered in the shaded boxes).

On the demand side, it has been well documented that, as incomes rise, people tend to initially consume more food (\( \epsilon_{DY}(y) \)) is the parameter capturing this effect—what economists term the income elasticity of demand for food)—but more importantly, as incomes rise, they tend to shift their consumption pattern towards more livestock-based products (Pingali 2007). This has important consequences for land use, as livestock—particularly beef animals—can be blunt converters of land into food (Eshel et al 2014). In addition to being responsive to changing incomes, consumer demands are also price-responsive, with the absolute value of price responsiveness—what economists call the price elasticity of food demand, \( \epsilon_{DY}(y) \), tending to diminish as consumers become wealthier (Muhammad et al 2011). This is reflected in the fact that this price elasticity is itself a function of per capita income. High income consumers can largely ignore a rise in price of a commodity (e.g. rice) which absorbs just a small share of their total budget, whereas low income consumers must adjust by either consuming less food or switching to cheaper calories.

Economic factors also play a role on the supply side of the global food economy, as portrayed in the lower half of figure 1. As land becomes increasingly scarce in the face of growing demands, land prices, and the associated annual payments required by those renting farm land, rise. During boom periods, these land rental responses can be very large (Henderson 2011), and they send the signal to farmers to conserve land by intensifying production (\( \epsilon_{SI} \) is the price elasticity of supply at the intensive margin—i.e. how price-responsive are crop yields). In the long run, research and development as well as the diffusion of agricultural technologies have been shown to be responsive to relative prices as well (Ruttan 1977); this has the effect of further increasing the value of \( \epsilon_{SI} \).

### Table 1. Economic mechanisms shaping land use change and leakage.

| Model description                      | Key economic mechanisms at work                                                   | Economic parameters                                      |
|----------------------------------------|-----------------------------------------------------------------------------------|----------------------------------------------------------|
| Unified global model                   | The price-responsiveness of yields as well as consumer demand dampen the extent of cropland expansion in the face of growing demands | Ease of substitution between land and nonland inputs & price elasticity of demand, both evaluated relative to the elasticity of cropland supply |
| Two region model with integrated markets | Developments in the treated region may spillover to untreated regions, thereby altering land use in the rest of the world. Impact of technology on global land use change is ambiguous | Excess demand elasticity; this depends on the worldwide price elasticity of demand, the supply elasticity in the untreated region, and the share of global supply produced in the treated region |
| Multiple regions with market segmentation | Market segmentation blunts transmission of price changes in the treated region to the rest of the world, thereby decreasing the likelihood of lemons paradox | Ease of substitution between home and foreign goods; border policies |
| Bilateral geography of global trade    | Bilateral ‘geography’ of trade shapes the pattern of land use in the rest of the world following an intervention in the treated region | Ease of substitution between imports from different supply regions |
| General equilibrium analysis of land use and leakage | Evolving comparative advantage can lead to a shrinking (or expanding) agricultural sector | Ease of movement of labor and capital across sectors; relative labor/capital intensity of sectors interacting with changing factor availability |
The potential for intensification of crop production depends on a variety of agronomic and economic factors, and also on the current level of intensification. It is expected that, in parts of the world with very low levels of commercial inputs, a favorable development in prices (higher output prices, or lower input prices) could induce a significant supply response at this intensive margin as has been suggested to be the case in Malawi where significant fertilizer subsidies were introduced (Ricker-Gilbert et al. 2011). However, the magnitude of this response has been hotly debated and clearly depends on a variety of other local factors, including the extent of soil degradation (Messina et al. 2017). This raises a broader question about the extent to which biophysical and socio-economic constraints might alter the ability of producers to respond to higher prices at the intensive margin.

While many global economic models of land use change do not differentiate yield response by location, it is clearly a critical factor in environmental policy analysis. The greater the yield response to scarcity, the less the need to convert natural lands to cropland in the face of shocks such as the US biofuels boom. Golub and Hertel (2012) show that allowing yield response in the non-US regions to depart from the US-based estimates in the widely used GTAP-BIO model results in dramatically different estimates of global land use and terrestrial carbon emissions flowing from US biofuels mandates. They conclude that more geographically-specific estimates of the endogenous intensification parameter, $\varepsilon_{SI}$, are required. Havlik et al (2013) have sought to introduce regional heterogeneity into their global model by explicitly modeling the biophysical and economic systems at the grid cell and then aggregating these to the national and global levels in the GLOBIOM model. Their linear programming approach is an important start, however, I believe it is fair to say that much more research is required to accurately estimate location-specific intensive margins of supply response across the globe.

The final piece of this economic puzzle is the responsiveness of cropland supply to increased returns in farming, a parameter which economists term the price elasticity of supply at the extensive margin, $\varepsilon_{SX}$. It is shown at the bottom of figure 1. Note that, in this simplified, long run, partial equilibrium framework, we assume that the nonland inputs are in ‘perfectly elastic’ supply. That is to say, their price remains unaffected by developments in the farm sector, but is instead determined by developments in the rest of the economy. We will discuss the limitation of this assumption when we turn to the general equilibrium framework at the bottom of table 1.

All of these economic elements can be combined to allow for an analytical, partial equilibrium solution to this unified agricultural model in which the long run change in cropland, $q_L^*$, depends on the exogenous shocks to demand, $\Delta_D$, as well as exogenous trends in yields due to improvements in agricultural technology, $\Delta_L$, along with the three economic margins of response to price:

$$q_L^* = \frac{(\Delta_D - \Delta_L)}{1 + \frac{\varepsilon_{SI}}{\varepsilon_{SX}} + \frac{\varepsilon_{DP}}{\varepsilon_{SX}}}.$$  \hspace{1cm} (1)

Equation (1) reveals several important points about global cropland change in the long run. Firstly, since all of the price elasticities have been defined to be positive, their presence in the denominator of (1) serves as a shock absorber to global land use changes in response to changes in the net demand for cropland, $(\Delta_D-\Delta_L)$. If the world finds itself in
a period where the demand for cropland is outstripping yield improvements and innovations, then prices will rise, households will curb consumption or shift to less land-intensive diets (e.g. less beef), and farmers will intensify production. All of this leads to a moderation of the amount of additional land actually brought into production.

A second point to note from equation (1) is that what matters for land conversion is not the absolute size of the price elasticities of demand and supply, but rather the relative size of the demand and intensive (yield response) supply elasticities, as compared to the extensive (area response) supply response. There are many examples of biophysical models of global cropland change which do not incorporate the demand and intensive supply margins into their long run projections. Historically, the GCAM (Wise and Calvin 2011), IMAGE (PBL Netherlands Environmental Assessment Agency 2015) and PIK models (Lotze-Campen et al 2008) all fell into this category—although more recent versions have sought to remedy this limitation in various ways3. From equation (1) if the modeler assumes that \( \varepsilon_{SI} = \varepsilon_{DP} = 0 \) then when net demand rises by 10%, (productivity adjusted) global cropland must also rise by 10%.

Baldos and Hertel (2013) explore the implications of ignoring these economic margins of response in the context of the 1961–2006 historical period for the global food economy (1961 is when the FAO data series begins, and 2006 is the year before the global food price crisis). They first introduce the SIMPLE model (a Simplified International Model of Prices, Land use and the Environment) and validate it against global data over this period. SIMPLE is just a numerical implementation of the framework in figure 1, with supply and demand developed at the level of 15 geographic regions and exogenously specified growth in population, income and productivity. The authors find that, when they rerun the model over this historical period with the demand and intensive supply margins eliminated, the model over-predicts historical land use change by nearly three times. This illustrates the point, already evident from equation (1), that purely biophysical models will overstate cropland changes in response to exogenous shocks. This follows directly from the missing adjustments in consumer demand and producer yields in response to higher prices. It also helps to explain why some of the most prominent Integrated Assessment Models predict considerable expansion in cropland over the 21 century (Schmitz et al 2014) despite slowing population growth (UN Population Division 2015) and robust growth in agricultural productivity growth (Fuglie 2010). In short, land change scientists ignore economic responses to scarcity at their peril, when undertaking long run projections of land use change.

Two-region model: international trade creates opportunities for landuse spillovers to other regions

Thus far we have abstracted from international trade by assuming a unified global economy in which any shock—e.g. an improvement in technology—applies worldwide. However, most of the empirical literature on land use spillovers and leakage focuses on the case wherein producers in one region are ‘treated’ with technological change or conservation set aside, and the remainder of the global economy is untreated (Angelsen and Kaimowitz 2001, Gasparri et al 2015, le Polain de Waroux et al 2017). Here, economic theory can again provide a useful guide to understanding the conditions under which improvements in agricultural technology will lead to land expansion in the treated region, as well as globally.

In this second model (second row of table 1), we start with the extreme case in which world markets for agricultural products are fully integrated. This specification might be termed ‘trade economists’ nirvana’ since it reflects a global economy in which each product can be purchased for the same price, regardless of the country/region. So we are abstracting from transport costs, tariffs and other government policies aimed at insulating domestic producers and/or consumers from developments in world markets. This situation is portrayed in the three panel diagram in figure 2. The left-most panel portrays the agricultural supply curve in the innovating region (A) via an outward shift in the quantity supplied for any given price. The middle panel portrays the global market equilibrium under integrated markets wherein region A’s supply is added to that from the rest of the world (RoW) in the right hand panel to obtain a global supply curve. The intersection of global supply and demand determines price, which naturally falls in response to the increased product supply coming from region A.

In this framework, the sufficient statistic for determining the direction of land use change in the treated region, in response to an improvement in agricultural technology, is the absolute value of the price elasticity of excess demand, \( \varepsilon_{DP}^T \), facing producers in the treated region (Hertel et al 2014). This elasticity describes the slope of the demand curve facing producers in the innovating region. It is given by equation (2), and depends not only on global demand conditions, but also on the responsiveness of producers in the rest of the world to price changes emanating from the innovating region. When \( \varepsilon_{DP}^T \) is large, producers in region A can expand production without significantly affecting the world price for the crop in question. When \( \varepsilon_{DP}^T \) is small,
the expansion drives prices down and quickly curbs the incentive for further expansion.

\[
\epsilon_{DP}^T = \frac{\left(\epsilon_{DP}^W + (1 - \alpha) \left(\epsilon_{SI}^{Row} + \epsilon_{SX}^{Row}\right)\right)}{\alpha}. \tag{2}
\]

As can be seen from (2), the size of the excess demand elasticity is determined by three factors: (a) the responsiveness of consumer demand around the world to changes in the product price, as represented by the absolute value of the world price elasticity of demand for the agricultural product, \(\epsilon_{DP}^W\), (b) the potential for producers in the rest of the world to respond to price changes, as summarized by the total supply elasticity in the rest of the world, \(\epsilon_{SI}^{Row} + \epsilon_{SX}^{Row}\), and (c) the share of global supply provided by the treated region, \(\alpha\). The larger are the first two parameters, and the smaller is the share of global supply derived from the treated region, the larger will be the excess demand elasticity. It can be shown (Hertel et al 2014) that the critical value for determining the direction of land use change in the treated region is \(\epsilon_{DP}^T = 1\). When \(\epsilon_{DP}^T > 1\), improvements in productivity will lead to cropland expansion in the treated region, and when \(\epsilon_{DP}^T < 1\), the price depressing effect of output expansion will curb expansion such that the efficiency gains of the new technology outweigh the effect of increased output and land use in the treated region will contract.

This analytical framework is extremely useful in sorting out the literature which emerged from the ‘Borlaug-Jevons’ debate over the land use impacts of agricultural technology change (Hertel et al 2014). First of all, from (2) it is clear that, contrary to assertions in much of the early literature on this topic (Angelsen and Kaimowitz 2001), the question is not just what the global demand conditions are for the innovated product, the supply response in the rest of the world is also critically important. Secondly, note the important role of \(\alpha\) in (2). If the innovating region has only a small share of the global market, it is more likely that \(\epsilon_{DP}^T > 1\) and land expansion will occur in the treated region. This can be termed ‘the importance of being an unimportant producer in the world market’. Under these conditions, land use expansion in the innovating region becomes more likely.

Up to this point, we have not addressed the fundamental question of global land use. This was at the heart of Borlaug’s assertion (Borlaug 2007) that the green revolution had spared land globally. Determination of the conditions under which improved technology in one region will spare land globally is necessarily more complex than determination of land use change in the treated region alone. Economic theory dictates that, with a lower world price, output and land use will fall in the untreated region in the wake of the new technology. However, this could be offset by a rise in land use in the treated region. Ultimately Borlaug’s hypothesis requires testing in an empirical context. (See the related paper in this volume by Nelson Villoria.) However, if we make the simplifying assumption that the supply conditions are the same in both regions, we can derive expression (3) which highlights the critical role of relative yields in this outcome. This equation states that, under the condition of uniform supply elasticities, when the price elasticity of world demand for the crop in question exceeds a weighted combination of relative yields in this outcome. This equation states that, under the condition of uniform supply elasticities, when the price elasticity of world demand for the crop in question exceeds a weighted combination of relative yields in the treated region vs. globally \(\left(\frac{Y^A}{Y^W}\right)\), and the globally uniform total supply response to price, \(\epsilon_{SI}^W\). Borlaug’s hypothesis will be overturned:

\[
\epsilon_{DP}^T > \left(\frac{Y^A}{Y^W}\right) (\epsilon_{SI}^W + \epsilon_{SX}^W) \Rightarrow \text{reject Borlaug}. \tag{3}
\]

It is easy to see from (3), that if yields were the same between the treated and untreated regions, then the terms involving the supply elasticity would cancel and the critical value for Borlaug’s assertion to hold is that the price elasticity of demand for the crop in question is less than one. Since this is true for most staple foods in most regions (Muhammad et al 2011), given the Green Revolution’s emphasis on staple grains, Borlaug would seem to be strongly supported by the result in (3).
However, in reality we expect the yields in the two regions to be unequal. In particular, consider the case where yields in the treated region are far lower than the world average, i.e. \( \frac{Y_{\text{tr}}}{Y_W} \ll 1 \). This opens the possibility of Jevons’ paradox applying at global scale. Hertel et al (2014) explore this possibility in greater detail using the SIMPLE model referenced above, and relaxing the restrictive assumptions about equal supply responses in the two regions. They find that, while the historical Green Revolution did indeed spare land globally, a prospective African Green Revolution might not have the same benefit if it began today due to the very low relative crop yields in Sub-Saharan Africa.

Segmented markets: product differentiation blunts the cross-border transmission of price signals

The (increasingly challenged) efforts of the World Trade Organization notwithstanding, the world is a long way from the stylized model of perfectly integrated markets postulated in the foregoing analysis. This is particularly true for agricultural products where government interventions remain pervasive. Indeed agriculture is one of the primary reasons why the Doha Round of WTO trade negotiations remains in flux, nearly two decades after its inception (WTO 2018).

In some regions—most notably parts of sub Saharan Africa (SSA)—there is the added challenge of physical access to markets. Producers and consumers are isolated—not only from international markets, but also from their own national markets (Porteus 2015). We adopt the term ‘market segmentation’ to refer to the situation in which markets are not fully connected and international prices are imperfectly transmitted into national and local markets—either due to government policies or poor infrastructure. This has the effect of reducing the excess demand elasticity in equation (2), thereby increasing the likelihood that an improvement in locally employed agricultural technology will reduce local cropland extent.

Regardless of the extent of market integration, we already know that, if the technological innovation in the treated region is the only perturbation to the system, cropland in the rest of the world must fall (or at least not rise, relative to baseline), due to the expected decline in world prices. Therefore, a simultaneous decline in land use in the treated region is a sufficient condition to satisfy the Borlaug hypothesis. So, by reducing the excess demand elasticity facing producers in the treated region, market segmentation reinforces the likelihood of Borlaug’s hypothesis being upheld. Hertel et al (2014) confirm this point empirically by examining the impact of a prospective African Green Revolution in the presence of historically segmented agricultural markets. They conclude that, under this historically segmented trade regime, such a Green Revolution would indeed be land-sparing, in contrast to the ambiguous outcome when markets are perfectly integrated.

Hertel and Baldos (2016) provide an in-depth analysis of the interplay between international trade governance, land use change and the consequences of sustainability policies. They begin by re-running the SIMPLE model over the period 1961–2006, assuming that markets had been fully integrated. In this case, agricultural output and cropland expand more slowly in Africa. This is the consequence of very slow growth in agricultural productivity in the SSA region over this historical period. Given the option, many African consumers would have preferred to consume cheaper food imports from abroad. Historical market segmentation meant that most of the growth in population in SSA was instead fed by expanding domestic production. In contrast, they consider what history would have looked like in a world of integrated markets and find this would have resulted in far more rapid growth in agricultural output and cropland in North America, where productivity growth was above the world average. In summary, the governance and functioning of international trade is critical in determining the consequences of technological change and environmental policies for land use change.

Introducing bilateral trade relationships: how the geography of international trade shapes patterns of indirect landuse change

The next economic concept explored in this paper (table 1, row 4) is that of rigidity in bilateral trade flows. There are many reasons for such rigidity, including geographical determinants of production (e.g. wine grapes from a specific region), infrastructure, distance, language and historical ties. In the late 1960s, while focusing on the determinants of international trade at the International Monetary Fund, economist Paul Armington was struck by the remarkable rigidity of bilateral trade relationships. Contrary to prevailing trade theory at the time, modest changes in export prices from one country did not result in dramatic shifts in trade patterns. This led to his seminal paper in which he developed a ‘theory of demand for products differentiated by place’ (Armington 1969). By distinguishing products by country of origin, and introducing imperfect substitutability between these products supplied from different countries, Armington obtained a model which fit the historical data on bilateral trade patterns remarkably well. While subsequent developments in trade theory (Krugman 1980, Melitz 2003) have greatly enriched the underlying theory, the empirical models derived from these theories remain reliant on this imperfect substitution between products originating...
from different sources (Anderson and van Wincoop 2003).

Of course, the extent to which different countries’ products substitute for one another is ultimately an empirical question, and there is a vast literature aimed at estimating these elasticities (Hillberry and Hummels 2013). Villoria and Hertel (2011) highlight the relationship between the so-called Armington elasticities of substitution in agricultural trade and patterns of indirect land use change induced by shocks to the US coarse grains market—either from the demand-side (e.g. biofuels) or from the supply side (e.g. drought or flooding). The model which they estimate allows them to test for integrated markets (recall row 2 in table 1)—an hypothesis which they soundly reject in favor of the Armington specification.

As a contribution to the literature on indirect land use change due to the US biofuels program, Villoria and Hertel (2011) contrast the ensuing global pattern of changes in land use and terrestrial carbon under the Armington vs. Integrated Markets specifications. They find that adopting the integrated markets model results in more land conversion and double the terrestrial GHG emissions, as compared to the empirically validated Armington model. By way of example, the integrated markets model, as was used in some of the most influential analyses in the biofuels/land use debate (Searchinger et al 2008), predicts far too much land conversion in India—a country which is effectively insulated from world markets by domestic policies. On the other hand, the integrated markets model predicts far too little land conversion in Canada—a country which shares a 3000 mile border with the United States and which is that country’s most important bilateral trading partner. In short, bilateral ties matter when it comes to international trade, and this is a factor which land change scientists must take into account in their analyses of spillovers. The world is not a ‘bathtub’ into which one can pour a commodity, removing it elsewhere with no regard to its origin.

### General equilibrium model: changes in comparative advantage alter land use

The final set of economic concepts (last row of table 1) are derived from general equilibrium economics. These considerations are brought into play via computable general equilibrium (CGE) models which are increasingly used in analyses of land use change (Stevenson et al 2013, Hertel et al 2009, Hertel et al 2010). By accounting for changes in all of the sectors in the economy, CGE models are able to capture relative changes in competitiveness of different industries, thereby accounting for changes in an economy’s comparative advantage.

A recent example of changing comparative advantage is offered by the opening of the Chinese economy, which, until the 1990s, was largely an agrarian economy with the majority of the population living in rural areas. With its entry into the world economy and subsequent accession to the WTO, China’s economy was encouraged to shift its pattern of production in favor of its comparative advantage on the world stage. With abundant labor, strong savings and growing foreign direct investment, China experienced a boom in manufacturing activity—quickly becoming the most important supplier to world markets. This, in turn, led to a dramatic increase in rural-urban migration—despite the Hukou system aimed at preventing rural migrants from adopting permanent residence in the cities (Chan and Zhang 1999). With exports booming, there was also pressure for China’s currency to appreciate in value. Both of these factors, along with tariff reductions under the WTO accession agreement, resulted in China’s farmers facing increasingly stiff competition from imports. With limited land, greater emphasis on environmental quality through the ‘Grain for Green Program’ (Delang and Yuan 2015), greater competition for labor, and cheaper imports, it is little surprise that the relative importance of agriculture has diminished in the Chinese economy—despite dramatic growth in subsidies for farming (Gale 2013). Indeed over the period: 2000 to 2014, imports of soybeans grew six-fold and the area devoted to cropland declined by about 2 million hectares (FAO 2014).

These developments in China are inherently general equilibrium in nature and reflect the evolution of this country’s economy in response to changes in its comparative advantage, coupled with an opening of the economy trade. Without modeling the entire economy, it is not possible to capture these changes. Recent work by Yao et al (2018) employs a modified version of the GTAP global CGE model to estimate the contribution of these general equilibrium forces to the growth in China’s soybean imports over the period: 2004–2011. They find that these economy-wide factors are far more important drivers of soybean imports than the more obvious factors such as changes in soybean productivity and agricultural policies. In short, there is a valuable role for CGE models in assessing the long run evolution of agriculture, and hence land use—particularly in rapidly growing economies where comparative advantage may be radically changing.

### Opportunities for collaboration between economists and land change scientists

The message from the foregoing analysis is clear—land change scientists stand to benefit from greater collaboration with economists—not only when it comes to
estimating the extent to which local interventions will create land use leakage and spillovers elsewhere—but also in constructing long run projections of land use change. However, speaking as an economist who has benefited greatly from collaborations with land change scientists over the past decade, the reverse is also true. There is a great deal for economists to learn from such inter-disciplinary work. But for such collaborations to be successful, the economists need to extend themselves beyond their usual comfort zone. For starters, it is necessary to become conversant in spatially explicit data and associated modeling approaches\(^5\). It is easy for those working with aggregated land use data to fall prey to the ecological fallacies (Robinson 2009) which arise when drawing conclusions about average rates of land use change when ecological and socioeconomic heterogeneity are key determinants of such changes (Godar et al 2016).

However, the potential benefits for economists run far deeper than simply disaggregating their models and include the emphasis which land change scientists place on the critical role of local institutions in determining where and how land use change arises (Meyfroidt et al 2014). Land change scientists are also generally more open to alternative behavioral assumptions—and the potential for heterogeneous agents to differentially shape patterns of land use change (Godar et al 2014). This is emphasized in the literature on ‘agent-based modeling’ where different groups of agents are assigned different objective functions and constraints (Matthews et al 2007). These are topics covered elsewhere in this special issue of Environmental Research Letters and I encourage my colleagues in economics to study them in detail and explore opportunities for collaboration with the rapidly growing community of land change scientists.

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ORCID iDs

Thomas W Hertel  
https://orcid.org/0000-0002-7179-7630

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\(^5\) For an economist’s critique of the spatial simplifications commonly employed by trade economists, the reader is referred to Paul Krugman’s remarks on the occasion of Alan Deardoff’s Festschrift (https://www.princeton.edu/~pkrugman/deardorff.pdf) where he suggests that the common practice of treating countries as ‘dimensionless points’ leads economists to miss much of the recent story in the development of international trade.

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