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Economic drivers of telecoupling and terrestrial carbon fluxes in the global soybean complex

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ABSTRACT

Telecoupling is a novel concept describing simultaneous multiscale interactions between human and natural systems across long distances. One important vehicle for telecoupling is international agricultural trade, which has previously been addressed using multiregional input-output (MRIO) methods. This study advances that work by accounting for market-mediating factors based on the GTAP-BIO model. We apply this framework to analyze the economic and environmental consequences of the Brazilian soybean boom. We decompose the drivers of this telecoupled system into five groups – macroeconomic growth, soybean productivity, other crop productivity, government policies, and pasture and forestry factors – quantifying each socio-economic driver's local and distant contributions to all human and natural changes in this system. We find that China's macroeconomic growth boosted soybean production and exports from Brazil and the US, whereas macroeconomic growth in the latter two regions actually dampened soybean exports over the 2004–2011 period under examination. Brazil's strong soybean productivity growth over this period, allowed that country to become dominant in the global soybean market. It also had strong spillover effects, displacing the US in the Chinese market and reducing overall growth in soybean output in the US. This strong soybean productivity growth also contributed to cropland expansion in Brazil.

1. Introduction

"Telecoupling" is a relatively new approach to conceptualizing simultaneous interactions between both micro- and macro-level drivers of economic and environmental change across long distances (Liu et al., 2013). International trade is one important element of "telecoupling" and has featured importantly in a number of recent studies of telecoupling. Pioneering work from Yu et al. (2013) used a global multi-regional input-output (MRIO) model to investigate the relationships between local consumption and global land use change. However, their MRIO model neglects market-mediating factors associated with economic responses to scarcity and ignores the role of technological progress. In this paper, we use a modified version of the Global Trade Analysis Project model (GTAP-BIO), which can be viewed as an economic extension of MRIO analysis that captures interactive supply-demand relationships both locally and globally, traces market-mediated responses to resource constraints, and takes into account technological progress. It emphasizes the role that international trade plays in mediating between different land use and environmental outcomes across the globe – hence the relevance to telecoupling. A particularly attractive feature of this framework is that it allows for the quantification of the relative contribution of each socio-economic driver to observed telecoupling between different regions.

The telecoupling concept has evolved from the literature on Coupled Human and Natural Systems (CHANS) (Wang and Liu, 2016). Previously, each CHANS was treated as a closed system (Carpenter et al., 2009; Monticino et al., 2007; Moran, 2011; Ostrom and Nagendra, 2006; Shaver et al., 2015). For example, Gasparri et al. (2013) investigate the linkages between the soybean economy, cattle ranching, and deforestation in Argentina. Telecoupling further connects each CHANS through inter-regional flows and expands them into a globally-interacting framework. In a telecoupled framework, each CHANS is treated as an open system, in which the agents interact with agents in other CHANS (Wang and Liu, 2016). Current telecoupling studies have been mainly theoretical in nature with few empirical applications (Eakin et al., 2014; Liu et al., 2015a, 2015b, 2013) and many have called for more empirically based, global-level human-nature research (Liu et al., 2007, 2013).

The international soybean economy provides a good example of a telecoupled system with significant global environmental change implications. A stylized description of this system is shown in Fig. 1. It involves three major players: China, Brazil, and the US. China is the

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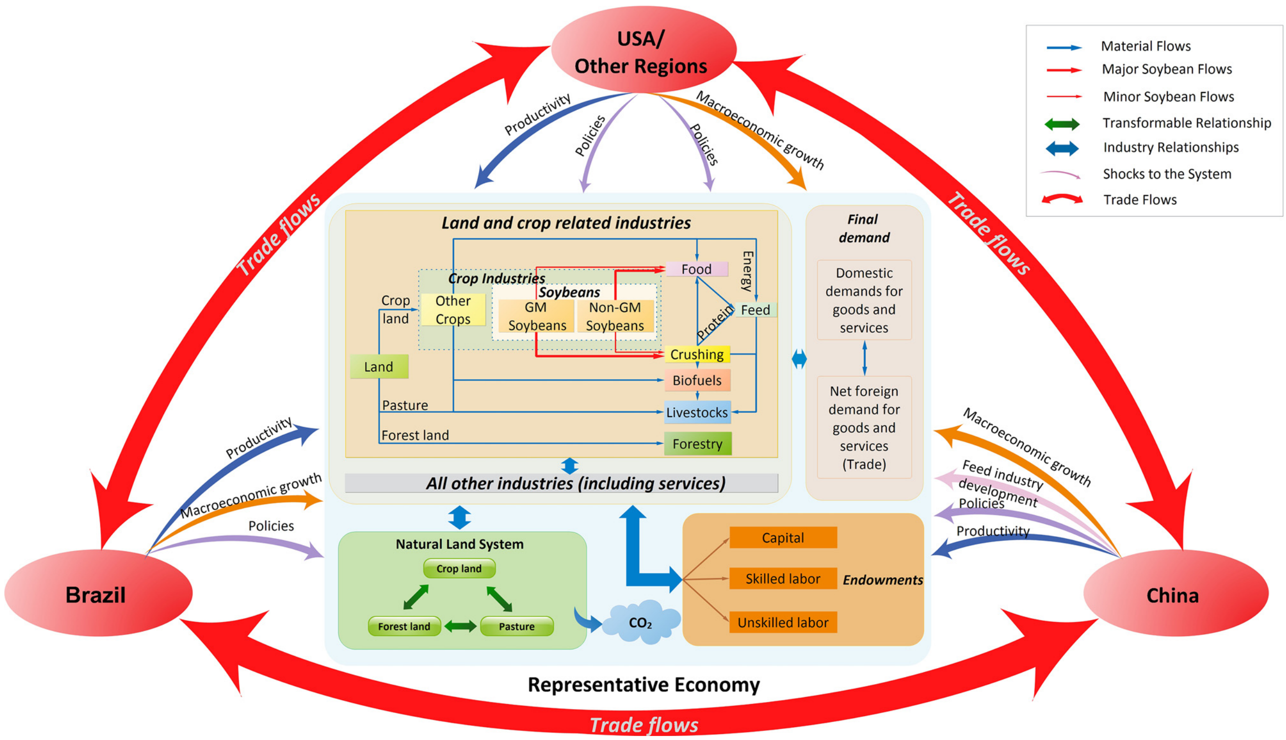

Fig. 1. Telecoupling conceptual framework for analyses of the soybean trading system. Brazil, China, and the US are connected through trade flows. China's economic growth generates strong demand for soybean production. Meanwhile, Brazil's agricultural productivity has further facilitated soybean growth. Domestic and trade policies mediate these supply and demand relationships. The graphic in the middle shows the soybean production and marketing system in a representative national economy in our model. Arrows refer to input flows. Thick arrows represent primary flows while thin arrow lines represent secondary (lower volume) flows. Red arrows highlight soybean flows, and blue arrows are other general flows. Colored curved arrows originate from each system and denote socio-economic drivers that incentivize soybean production (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

world's largest soybean importer; Brazil and the US are the two largest soybean producers and exporters. They are connected through trade flows. In this research, we primarily investigate Brazil-China soybean trade relationship and its major spillover impact on the US. In this context, Christofoletti et al. (2012) find that China developed strong price linkages with the US, Brazil, and Argentina after 2006, and that the US prices adjusted more rapidly than other countries. By analyzing the evolution of China-Brazil soybean trade and its implications for land use in these two countries, Torres et al. (2017) conclude that international soybean trade enabled China to conserve its forests and biodiversity while transferring these pressures to Brazil's natural ecosystems. Silva et al. (2017) also focus on the China-Brazil telecoupled system. They conclude that soybean production in Brazil incentivized maize-soybean rotation and increased maize production, which subsequently brought local pressures on Brazil's domestic stocks and supplies. They emphasize the need for further investigations of the socio-economic drivers of telecoupling. Sun et al. (2017) mapped finer-scale spatial distribution of soybean land use changes in China, Brazil and the US. They aim to motivate further studies of international trade relationships and the ensuing land use changes. Our paper takes up this challenge and provides an empirical analysis of the trade linkages between these three countries. More specifically, our analysis of the telecoupled soybean system brings to bear not only the drivers of change within the soybean industry itself, but also key changes in related sectors – including the feedstuffs industry and livestock production in China, biofuels produced across the world, changes in agricultural and trade policies, exogenous and endogenous price induced technological progress, as well as macroeconomic growth.

Studying soybean production and trade using a comprehensive telecoupling framework advances the previous soybean system literature that has typically focused on either the supply or the demand side of the system, while neglecting their interconnections at regional and global scales – the spillover impacts. Research focusing on the supply side frequently compares soybean production and marketing in the US, Brazil, and Argentina. US variable production costs are typically lower and farms are better connected to the international transportation system than in Brazil and Argentina (Sutton et al., 2005). However, abundant land – and the ensuing low prices for land – is the factor which ultimately favors Argentina and Brazil (Leibold and Osaki, 2009; Sutton et al., 2005). In addition, the US corn ethanol program led some US farmers to reduce soybean plantings in favor of corn production (Hauser, 2002). Meanwhile, Political reforms, more engagement in international business, improvements in transportation systems, farm management improvements, the government supports, and favorable climate conditions have helped Brazil to rapidly expand soybean production during the past two decades (Schnepf et al., 2001; Sutton et al., 2005). As a result, in 2013, Brazil surpassed the US as the largest soybean exporter in the world and this rapid growth in soybean area has, in turn, given rise to concerns about the environmental consequences, including potential loss of biodiversity and release of terrestrial carbon through increased rates of deforestation (Brown et al., 2005; Fehlenberg et al., 2017; Hecht and Mann, 2008; Morton et al., 2006; Richards et al., 2014, 2012; Walker et al., 2009). Recent analyses suggest much of this environmental degradation has been fueled by China's growing demand for soybean imports (Beckman et al., 2017; Garcia and Ballester, 2016; Grecchi et al., 2014; Richards et al., 2012). Despite the gradual decoupling relationship between soybean production and deforestation, soybean production may continue to result in deforestation though indirect linkages, such as livestock displacements as well as capital and skill movements in agricultural and livestock sectors (Arima et al., 2011; Barona et al., 2010; Gasparri et al., 2013; Richards, 2012; Richards et al., 2014). However, an explicit decomposition of the factors driving this growth in international soybean trade is thus far missing from the literature.