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The new economic geography of land use change: Supply chain configurations and land use in the Brazilian Amazon

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ABSTRACT

In this paper we present a framework for understanding regional land use processes by incorporating the concept of agglomeration economies into agricultural frontier theory. We show that agricultural firms can obtain positive externalities from locating in close proximity to other agricultural firms, leading to agglomeration economies. Agglomeration economies lead to high levels of competition and diversity within a local agricultural supply chain and influence local prices, information flows, and private enforcement of environmental institutions. We use the theory of agglomeration economies to understand the development of soybean production in two counties along the Santarém-Cuiaba (BR-163) highway in the Brazilian Amazon: Santarém, Pará and Sorriso, Mato Grosso. We conclude that differences in environmental and land tenure institutions influenced the occurrence of agglomeration economies in these two counties, which in turn affected the total factor productivity of soy in each region. In particular, the supply chain became extremely competitive and diverse in Sorriso where few environmental regulations existed, while environmental restrictions reduced the diversification of the supply chain in Santarém. The presence of a soy agglomeration economy in Sorriso spurred innovation, increased productivity, and led to extremely rapid soy expansion in that county, while the monopolistic supply chain in Santarém reduced producers' access to land and capital and impeded soy expansion.

Introduction

Soybean production in Brazil has received considerable attention in the last decade for its contribution to economic growth and environmental degradation in the Cerrado and Amazon. Soybeans have been planted on 700,000 km^2 in the legal[1] Amazon, contributing both directly and indirectly to deforestation in the region (Arima et al., 2011; Macedo et al., 2012; Morton et al., 2006). It is estimated that another 700,000 km^2 in the region could be physically and economically suitable for production when the pavement of the Cuiaba-Santarém highway (BR-163) is completed, allowing soy from Mato Grosso to be transported north to the port in Santarém, rather than south to Santos and Paranagua or west to Porto Velho (Fig. 1) (Fearnside, 2007; Vera-Diaz et al., 2009). Predicting how soy production will develop in the legal Amazon requires a better understanding of regional variations in soybean profitability and the actors involved in soybean production.

While previous studies have examined the impact of soybean expansion on deforestation (Meuller, 2003; Jepson, 2006a,b; Morton et al., 2006; Barona et al., 2010; Arima et al., 2011; Macedo et al., 2012) few studies have examined the *underlying* economic and institutional causes of soybean area expansion in Brazil beyond temporal fluctuations in prices and exchange rates (Macedo et al., 2012; Richards et al., 2012). The existing land use literature on Brazil has focused primarily on small-holders and on the role of household demographics, government programs, roads, and institutional arrangements (Rindfuss et al., 2007). Intensive mechanized soy production demands a different set of skills than smallholder agriculture, entails a higher level of financial risk, and requires access to large amounts of capital. Annual profitability is dependent on access to volatile international markets for soy and fertilizers and local production technologies evolve rapidly.

The objective of this study is to understand the development of industrial agricultural frontiers in Brazil better using theory from

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[1] Includes portions of Mato Grosso, Tocantins, and Maranhão not considered part of the Amazon biome.

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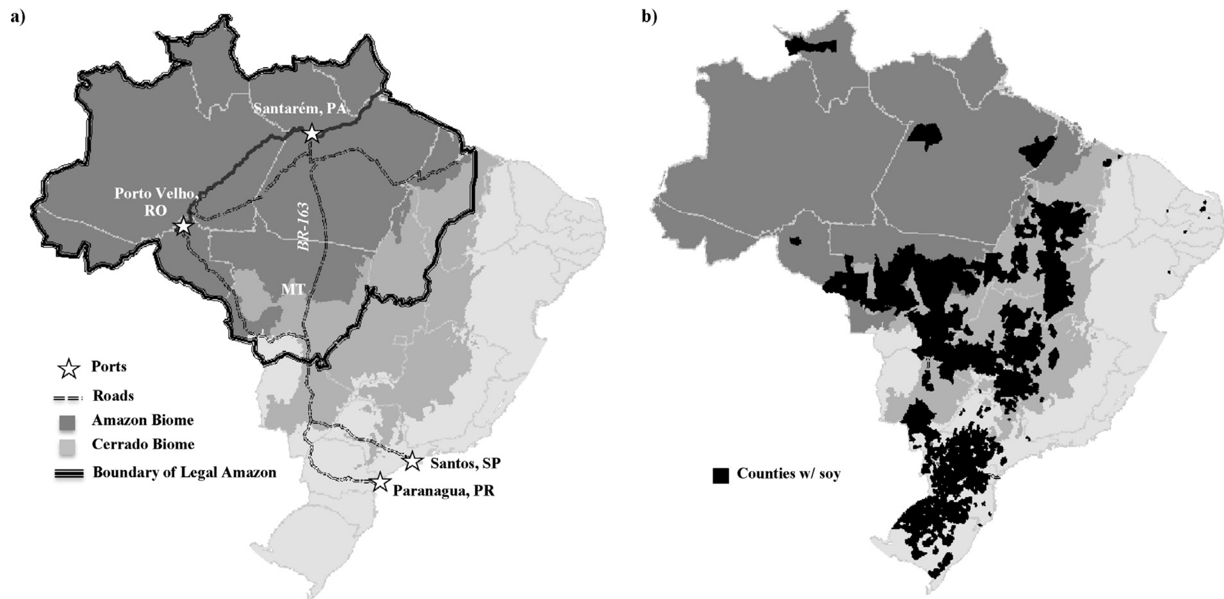

Fig. 1. (a) Key ports and transportation networks for Northern Mato Grosso, biome classifications, and the Legal Amazon boundary. (b) Counties in Brazil where soybeans are planted according to the 2010 IBGE Agricultural Production survey.

the field of “new economic geography” as defined by Krugman (1998).[2] In particular we propose a theoretical framework for understanding how supply chain configurations interact with local institutions, biophysical conditions, and transportation infrastructure to affect local agricultural prices, technology, and flows of information to farmers based on the literature regarding *agglomeration economies* and *clusters* (Hoover, 1948; Krugman, 1991, 1998; Marshall, 1920; Porter, 1990, 1998, 2000a). This framework characterizes local land use as a function of the concentration and diversity of various supply chain actors in the region, not just biophysical yield potential and transportation costs as predicted by Ricardian and Thunian theories of rent. It therefore represents an extension of these economic theories of land use.

We begin by briefly discussing Ricardian and Thunian theories of land use and describe why the recent extensions of these theories may be insufficient for understanding land use processes in the legal Amazon and in other rapidly developing agricultural regions. Next we explain the concepts of agglomeration economies and clusters in the agricultural sector and discuss how underlying biophysical conditions and transportation infrastructure can influence where agglomeration economies occur. We also examine how local supply chain configurations can influence agricultural profitability and local enforcement of environmental institutions by private companies. Finally, we introduce a comparative case study of two counties in the BR-163 corridor – Santarém, Pará and Sorriso, Mato Grosso – to illustrate how the concept of agglomeration economies helps explain different levels of soybean production in these two regions. We conclude by discussing how future changes in the supply chain configurations along the BR-163 corridor in the Amazon may influence soybean development in the region.

[2] We acknowledge that the field of “new economic geography” is no longer actually new (it is rather “middle aged” (Krugman, 2010), but the title still offers an important distinction from “old” economic geography (namely location theory) in that it incorporates general equilibrium dynamics, allowing for prices to be endogenous to the behaviors of producers. This distinction is critical because it acknowledges that competition can influence prices.

Theory

Existing theoretical framework of land use

Most economic land use models assume that land operators use their land in a way that will result in the largest expected profit after taking into account conversion costs between different uses. The profit of different land uses is in turn modeled as a function of the underlying value or “rent” of the land, rather than based on individual characteristics of the land operators (agents). Agents are assumed to buy their inputs and sell their goods at identical prices, have equal information, uniform production functions, and similar access to capital (Garrison and Marble, 1957). As a result of these assumptions it is possible to remove individual agents from these models and examine land use relationships at a broader scale.

For example, under the Ricardian framework, rents are determined exclusively by biophysical conditions (temperature, precipitation, and soil), which affect the maximum potential yield of agriculture, and by the relative scarcity of land with high quality biophysical characteristics (Ricardo, 1976). In contrast, Thunian theory states that, in an area of spatially uniform fertility, rent is determined by its distance to markets or transportation costs, which affect regional input and output prices for agriculture (Jones, 1978). Input and output prices influence rents directly by determining profits for a given level of production or indirectly by determining the economically optimal use of inputs (Kellerman, 1989).

A new economic geography of land use

Although Thunian theory has been adapted to incorporate the influence of government policy, speculation, and global market dynamics on expected land rents, few analyses, with the except of Jepson (2006a,b), acknowledge the role of individual actors, informal networks, or formal organizations in determining local land rents in Brazil. For example, Walker et al. (2009) and Walker (2011) discuss how expectations of land rents can be influenced by government subsidies and global changes in demand, but they also assume that local prices and yields are not influenced by local processes of competition. This assumption is unwarranted in the Brazilian Amazon and Cerrado given the fact that agricultural landscapes in these regions can greatly differ in their diversity of land use agents, producer groups, and formal agribusiness and agricultural organizations. The colonization of new agricultural zones is often pioneered by a limited number of producers, and only slowly populated with more supply chain actors. Ignoring these local social and economic dynamics allows modelers to scale up their analyses beyond the individual household, but masks local variations in economic and institutional conditions that maybe critical for farmers' productivity and profitability, such as market competition, information flows between actors, technical knowledge, and rules of access to resources and markets.

While land change science has largely overlooked these processes, the field of new economic geography has not. The literature on agglomeration economies and clusters shows that the number and diversity of companies and organizations located in close geographic proximity to each other influences competition and information flows between firms (Garrison and Marble, 1957; Krugman, 1998; Marshall, 1920; Porter, 2000b). When many related firms are located in close proximity to each other, this is known as a "cluster" or "agglomeration" of firms and organizations (Porter, 2000a). The clustering of related firms and organizations can result in positive externalities, such as increased transfer of knowledge regarding market conditions and new technologies, increased specialization, a pooled market for labor, lower transportation costs between firms, and reduced barriers to entry (Krugman, 1991, 1998; Porter, 1996, 2000b). No individual seller (or buyer) can leverage a superior market situation to set prices, and individual actors can buy and sell from a range of relatively equivalent firms (Webber and Labaste, 2010). Location within a cluster can help firms overcome credit constraints when credit from formal lending institutions is limited by increasing firms' access to alternative forms of credit (Long and Zhang, 2011). Intense competition requires firms to improve or maintain their strategic advantage on a continuing basis through investments in research and development, spurring innovation (Porter, 2000b). The positive externalities of locating close to other supply chain actors inside the cluster outweigh the negative effects of increased competition over local resources (Hoover, 1948; Krugman, 1991; Marshall, 1920; Piore and Sabel, 1984; Porter, 2000b).

Agglomeration economies in agriculture

Studies on agglomeration economies in the manufacturing sector model agricultural activities as a peripheral input, whose location is determined by exogenous transportation costs and biophysical conditions (Krugman, 1991). However, there is ample reason to believe that agglomeration economies can also develop within the agricultural sector. Our extension of the Fujitsa and Krugman (1995) conceptual model of circular causality in the spatial agglomeration describes how and why agglomeration economies can occur in the agricultural sector (Fig. 2). The model starts with a city in which agricultural producers have a higher income (output and profits) relative to adjacent areas due to superior biophysical conditions and transportation costs. The comparative advantage of this area relative to others incentivizes more producers to move into the region, which creates a greater demand for agricultural technologies and services. This greater demand allows specialized providers of these technologies and services to expand production, leading to economies of scale. The larger market of producers supports a wider variety of agricultural technology and service firms, leading to a greater variety of technologies and services available to the producers. The availability of these technologies and services further increases the total factor productivity of agriculture in that region, leading to higher profits. This in turn incentivizes more producers to move into the area, thus creating a positive feedback loop in agglomeration. Eventually land or water scarcity and high land and water prices begin to outweigh the benefits of further agglomeration. Agglomeration can be further inhibited if emerging resource constraints lead to the introduction of more strict environmental regulations.

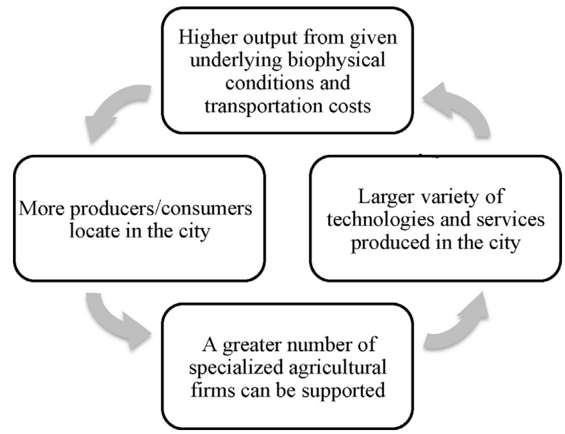

Fig. 2. Circular causality in the spatial agglomeration of agricultural firms and producers.
Adapted from Fujita and Krugman (1995).

There is already evidence from the wine (Porter, 2000b), organic vegetable (Eades, 2006), and hog (Roe et al., 2002) sectors in the United States that agricultural production and processing firms experience benefits from locating in close proximity to related firms. For example, Porter (2000b) shows that Northern California's competitive advantage in wine production is improved by the clustering of 680 wineries, thousands of independent producers, and numerous input manufacturers, public relation firms, advertising companies, and research organizations within a small region. Eades (2006) finds that the clustering of organic vegetable farms in California and New England helps producers coordinate with each other to engage wholesale regional markets and move beyond individual sales to consumers. A couple of agricultural studies in the United States and Mexico also demonstrate that social networks and knowledge systems, i.e., interactions between farmers and other supply chain actors, influence information flows and the propensity of producers to adopt new technologies (McCullough and Matson, 2011; Tomich et al., 2011; Warner, 2007). Within the context of Brazil, a handful of studies have found that access to cooperatives and the availability of credit impacts agricultural input and output prices (Sousa and Busch, 1998), soybean yields (Vera-Diaz et al., 2008), and soybean planted area (Garrett et al., 2012), without specifically using a cluster framework. In fact, Sousa and Busch (1998) describe the transformation of the Cerrado into an agricultural powerhouse as a process that was heavily influenced by the social networks and agribusiness partnerships (Sousa and Busch, 1998). Jepson (2006a,b) supports this view, providing evidence of how agricultural organizations were able to reduce information asymmetries, transaction costs, and risks associated with agricultural expansion in the Cerrado.

The existence of agglomeration economies in the agricultural sector implies that farmers operating in regions that have a large number and diversity of input venders should have lower input prices and better information and access to technology than farmers in regions with few input suppliers, all else equal. Similarly, farmers operating in regions with a large number and diversity of agribusinesses and credit providers should have greater access to credit and lower interest rates than farmers located in undeveloped supply chain regions because competition between agribusinesses and credit providers over customers can lead to novel credit arrangements and increase access to loans. Farmers operating in regions with a large number and diversity of soy consumers or purchasing companies should also have higher prices and access to a wider variety of soy markets than producers who are dependent on a single buyer. Competition at each node of the supply chain (input sales, credit provision, crop purchasing, etc.) can also lead to better information flows to farmers about prices and advanced marketing opportunities, such as environmental certifications.

Seed and chemical companies may focus their research and demonstration efforts in regions where there is a large concentration of farmers, relative to less densely developed regions, improving technological options and technological information in those areas relative to others. A clustering of diverse farming agents can lead to the development of new producer groups and agricultural non-governmental organizations, advancing new management practices and technical assistance in the region. In other words, competition and diversity can lead to enhanced innovation in agricultural production methods compared to areas with homogenous and monopolistic supply chain actors.

Supply chain configurations can also affect local environmental institutions and rule enforcement. The development of a diverse and powerful supply chain in a particular location may lead to more effective lobbying from that region and help producers there avoid stricter environmental regulations. Conversely, local branches of financial organizations, multinational grain trading companies, and non-profit organizations may lead to the creation or enforcement of stricter environmental rules, by requiring land operators to use specific management practices and meet existing environmental laws in order to receive credit, sell their products, or attain special certifications (Brannstrom, 2005; Brannstrom et al., 2012). Any change to the existing land use rules will influence expected profits by enhancing or constraining access to resources (Garrett et al., 2012). Furthermore, location within an agglomeration economy may enhance producers' understanding of and compliance with environmental regulations by increasing their access to environmental engineers and consultants that are specifically trained to help producers navigate changing environmental regulations.

While agglomeration economies may influence environmental rule creation and enforcement, environmental rules may also influence the location of agglomeration economies. Environmental institutions can influence where agribusinesses are willing to locate by creating regional comparative *dis*advantages. For example, in areas where government regulations limit overall land conversion, economies of scale for soy traders and processers will be limited. Additionally, the transaction costs of doing business will be higher in a region where the land use rules are very complicated or frequently changing, relative to a region that has few, stable environmental regulations.

Case studies

Design and case selection

We use a comparative case study design to explore the theories and hypotheses laid out in the preceding section, focusing on the counties of Sorriso, Mato Grosso and Santarém, Pará (Fig. 3). This design allows for a deep examination of the geographical, economic, and institutional context *within* each region and an examination of the heterogeneity *between* regions as means to understand potential causal relationships in both regions. We chose Sorriso and Santarém for study based on their location at opposite poles of the BR-163 corridor, a dynamic soy expansion frontier in the eastern Amazon, and because they represent "extreme cases" of supply chain development and environmental institutions. The use of extreme cases reduces the generalizability of each case, but

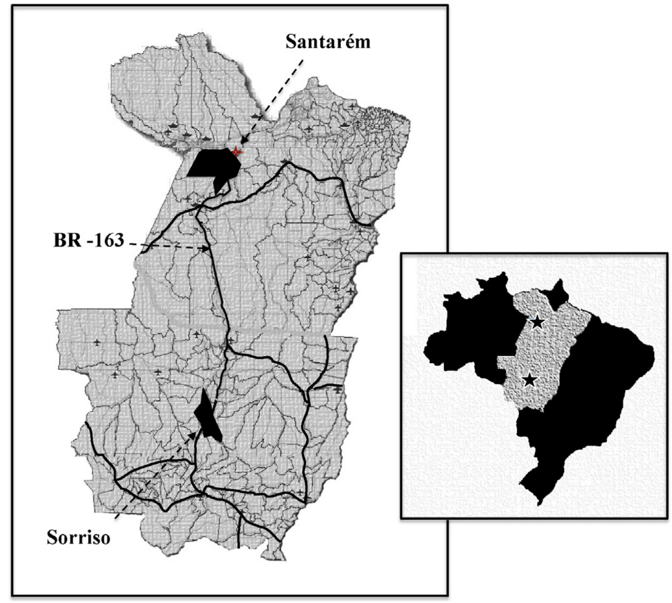

Fig. 3. Case study regions.

provides contrasting situations that allow for an illustration of theory with real world examples. The study design does not allow for any formal testing of the theory however.

Historical background

Santarém was first established as a settlement of pre-Columbian peoples in the 17th century (Stenborg et al., 2012). However, it was not until the 20th century that the area became more densely populated. During the 1960s and 1970s the federal government encouraged families from the Northeast of Brazil, among other areas, to relocate to the Amazon to help occupy the area and address concerns for land reform. Relocation efforts were located around the major federal highways (including the BR-163) and land distribution in these settlements was put under the jurisdiction of the National Institute of Colonization and Agrarian Reform (INCRA) (Schmink and Wood, 1992). The tenure regularization process for properties under the jurisdiction of INCRA is notoriously slow and bureaucratic, so many producers in the Amazon still lack definitive title despite having initiated the tenure regularization process many years ago (Ministério do Desenvolvimento Agrário, 2012).

Throughout the 1970s and 1980s there was no soybean production in Santarém because of extremely high transportation costs to ports farther south. In 1999, however, Cargill won a bid to construct a soybean terminal in Santarém and by 2003 the port was completed. In the early 2000s soybean producers from Southern and Central Brazil began purchasing land in Santarém after hearing advertisements from Cargill about cheap land and high soy prices. Many soybean producers arriving in Santarém were met with hostility and resistance from the local population, who feared a loss in their lands and livelihoods from the arrival of soybean production in the region (Steward, 2007). Cargill soon became the center of an international discourse about the negative environmental impacts of soybean expansion in the Amazon and the subject of intense scrutiny by conservation groups.

In stark contrast to Santarém, the colonization process in Sorriso was driven mainly by the private sector. Although the Mato Grosso state government initiated land sales in the 1940s and continued to promote colonization through advertising and investments in transportation infrastructure, by the 1970s private colonization firms and cooperatives had taken over a majority of land distribution in the state (Jepson, 2006a,b; Rausch, 2013). Private colonization firms helped families from the South obtain land title in Mato Grosso by monitoring land markets, negotiating with public officials, and purchasing, demarcating, and occupying land (Jepson, 2006b).

Farmers from the South made their first land purchases in Sorriso in the 1970s, and by the end of the decade they had planted their first experimental rice, soy, corn, and cotton fields to determine the best varieties and fertilization (Dias and Burtoncello, 2003). At this time part of the start up cost for farming in the Cerrado was funded by the federal programs PROTERRA and POLOCENTRO. Soy planting did not start in earnest in Sorriso until 1981, when 500 ha were planted. By 1989 the soy area had reached 140,000 ha (Dias and Burtoncello, 2003). Soybean production has increased steadily since then, and continues to grow to this day. Unlike Santarém, there has been very little opposition to soybean production in Sorriso, and little intervention by international conservation groups or domestics NGOs.

Geographical background

Sorriso and Santarém both have large flat areas that are highly suitable for mechanized soybean production. Santarém receives about 2000 mm of rainfall a year, with average daily temperatures ranging from 22 to 31 °C. Sorriso receives 2250 mm of rainfall, with temperatures ranging from 15 to 37 °C. The soils in both regions are mainly Oxisols and Ultisols, which have high acidity and low levels of phosphorus and potassium. The major biophysical difference between the two regions is the latitude and growing season. Santarém is located at 2° South, with a growing season from January to August, while Sorriso is located at 12° South, with a growing season from September to March. Between 2000 and 2010 soy yields averaged 3.1 MT/ha in Sorriso and 2.8 MT/ha in Santarém (Brazil's average soy yield was 2.6 MT/ha during this same period) (IBGE, 2010).

The dominant land cover in Santarém is primary and secondary forest (50% of the area), followed by pasture (3% of the area). Less than 1% of the total area of Santarém is planted in soy (28,500 ha).[3] There are 15,760 ha planted in rice and 7540 ha in corn. Santarém has a population of approximately 295,000, with 13 people per square kilometer and more than 70% of the population residing in urban areas. The GDP per capita in Santarém is roughly US$ 4000.

In Sorriso, the dominant land cover is soybean double cropped with corn, with 590,000 ha planted in soy (63% of the area) and 230,120 ha planted in corn (25% of the area). Natural woods or forest cover 13% of the area, while pastures occupy less than 5%. In 2010, Sorriso has a population of approximately 67,000, with roughly 7 people per square kilometer and 90% of the population residing in urban areas. The GDP per capita in Sorriso is roughly US$ 18,000.

Sorriso and Santarém are separated by 1400 km on the BR-163 highway, which is largely unpaved in the state of Pará, making travel between the two regions very difficult during the rainy season. Santarém producers have direct access to a deep-water port built and operated by Cargill, from which soy is transported directly to Europe. In contrast, the soy produced in Sorriso normally travels 2200 km by truck to ports in the Southeast (Santos and Paranagua). The cost of transporting a ton of soy from Sorriso to the southern ports ranges from US$ 100–150 (Vera-Diaz et al., 2009), while the cost of transporting soy from farms in Santarém to the Cargill port are negligible, roughly US$ 1/ton. Imported phosphorus arriving in Sorriso is generally mixed in Rondonopolis before arriving in northern Mato Grosso by truck, more than 2000 km away from any port. Phosphorus arriving in Santarém must be imported by river via ports on the east coast of Brazil, such as Belém, more than 700 km away or transported by truck from points south when conditions are passable on the BR-163. Thus fertilizer prices can be slightly lower in Sorriso than in Santarém. Since central Mato Grosso has large lime deposits, lime costs are substantially lower in Sorriso than Santarém.

Materials and methods

The lead author conducted interviews with more than 70 soy producers and numerous local experts in Sorriso and Santarém between June 2010 and August 2011. The purpose of these interviews was to obtain qualitative and quantitative information about the soybeans supply chain, environmental institutions, and land tenure in the two regions. The producer survey included questions on land use, yields, management technologies, costs, and prices (descriptive statistics for all variables provided in Table 2). A snowball sampling method was used, to achieve a wide spatial distribution and representative sample of farm sizes. The sample covered 41 of the <800 producers in Sorriso and 119,505 ha (20%) of the soy area. The sample in Santarém covered 32 of the <200 producers and 13,403 ha (47%) of the soy area. Due to accessibility issues, there was an oversampling of larger farms in both regions, and farmers who worked at or owned input stores in Sorriso. Interviews with other experts in the supply chain provided additional information on the relationship between private, government, and non-governmental organizations and farmers in the region. Supplemental information about land use and colonization in the two case regions was gathered from the Brazilian decennial agricultural census, annual municipal agricultural surveys, and primary documents obtained from municipal libraries in each county.

We used these interviews, secondary data, and primary documents to process trace[4] the causes and impacts of supply chain agglomeration (or lack of agglomeration) in the two counties. We also applied Student's two-sided *t*-tests to the data gathered from the farmer questionnaires to examine whether differences in supply chain configurations, technology, prices, yields, and profits in the two cases were statistically different. The combination of qualitative and quantitative methods allowed us to examine the complex interactions between the economic and institutional conditions within each region, while summarizing some of the key differences between the regions.

Results

Factors contributing to the development of agglomeration economies

Based on the biophysical suitability of the land (high yields) and the extremely low soybean transport costs in Santarém, one might expect Santarém to have high growth rates in soybean production since the installation of the Cargill port in 2003. Although

[3] Forest cover data is from 2011 from the Brazilian National Institute for Space Research. All other data are from the Brazilian Institute of Geography and Statistics. Planted area data are from the 2010 Municipal Agricultural Survey. Pasture area is from the 2006 Agricultural Census. Population data are from the 2010 Population Census. GDP data are from the 2010 Gross Domestic Product of Municipalities Survey. Reais are converted to US dollars using an exchange rate of 1.75 Reais per Dollar in 2010.

[4] Process tracing is defined by Collier (2011) as "the systematic examination of diagnostic evidence selected and analyzed in light of research questions and hypotheses posed by the investigator". Process tracing requires a deep knowledge and detailed description of each case and a focus on how events change over time within (or between) cases, with close attention to relationships between independent, dependent, and intervening variables. The ability to identify causal processes is dependent on having prior knowledge of how certain variables should relate through a theoretical frameworks or prior empirical evidence (Collier, 2011).

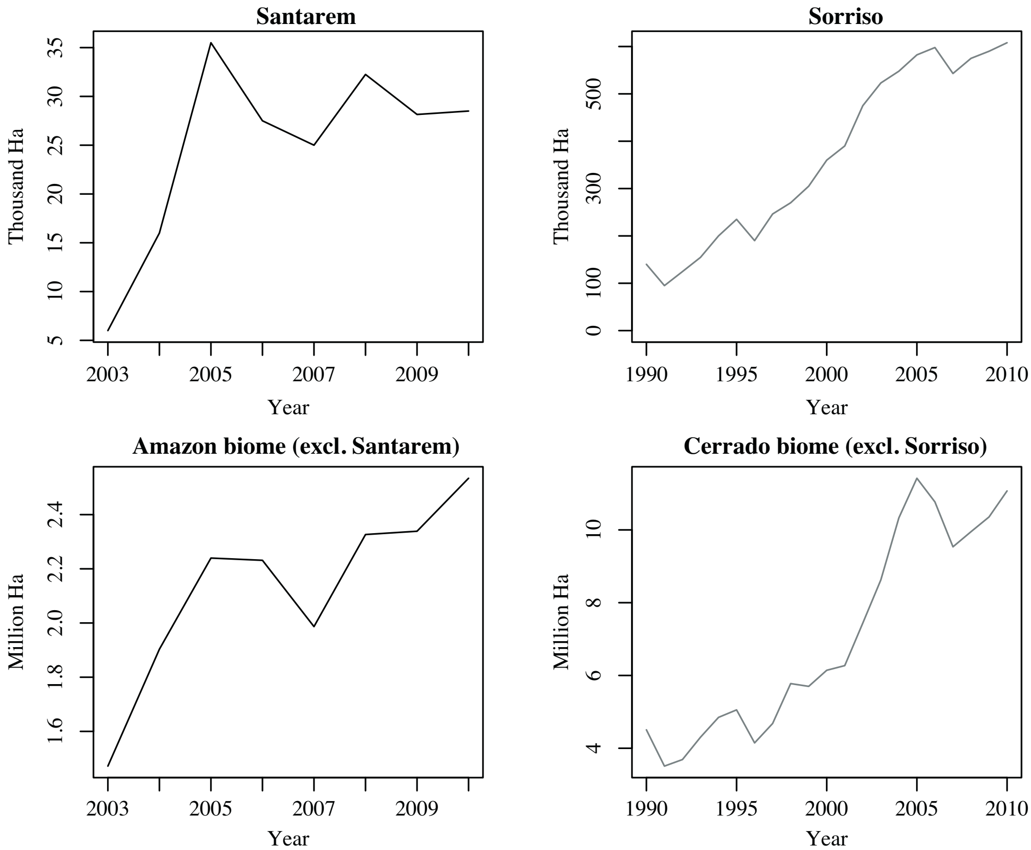

Fig. 4. Soy planted area in our two case study regions and in the larger Amazon and Cerrado biomes. All data come from the IBGE Municipal Agricultural Census. Values for Santarém include the county of Belterra. Values for the Amazon and Cerrado biome were calculated by allocating all or part of each county to a specific biome and weighting total planted area in that county by the proportion of that county that is in each biome.

average yields in Santarém over the past decade have been somewhat lower than Sorriso (2.8 versus 3.1 MT/ha), the price of soy received by producers should be much higher in Santarém, offsetting differences in rents between the two regions based on biophysical conditions and transportation costs alone. On the contrary, we see an initial explosion in soybean area after the port was completed, but then an overall decline in planted area, even as soybean planted area in other parts of the Amazon biome grew (Fig. 4). Santarém now has approximately 200 farmers producing 60,000 tons of soy on 28,500 ha (less than 1% of the total county area). In contrast, soybean production in Sorriso began in 1981 and increased continuously in the following three decades. Sorriso currently has around 800 soy producers, planting on 590,000 ha (more than 60% of the total county area), for a total production of roughly 2 million tons.

Furthermore, the supply chain in Santarém has barely evolved since the port was installed, while the supply chain in Sorriso has continuously developed since its initial colonization. Soybean planted area has continued to grow since the initial plantings in the 1980s (Fig. 4) and Sorriso now has a large number and diversity of soy businesses, while Santarém has very few firms. In Sorriso there are 14 major soy traders (*ADM, Bunge, Louis Dreyfuss, Multigrain, Maggi Group*, etc.) and numerous third party companies that provide marketing services. Sorriso producers are able to purchase inputs from more than 20 input resellers, 4 cooperatives, and directly from seed and fertilizer manufacturers and mixers. In Santarém there is only one cooperative (which was not actively trading soy at the time of our interviews) and one soy trader – *Cargill*. Producers have access to five local input resellers, but no direct access to fertilizer manufacturers and mixers. A local poultry rearing company, *Aves Pará*, also purchases a small amount of soy directly from farmers, but it is minimal compared to Cargill. Producers in Santarém often experience long delays in obtaining their seeds and fertilizers. They frequently cannot obtain the seed varieties they desire because the resellers run out of stock.

In addition to the greater diversity of physical input providers in Sorriso, there are more credit providers in Sorriso versus Santarém. Sorriso producers can obtain government subsidized loans for production and equipment from the *Bank of Brazil*, a federal bank, and *SICRED*, a local credit union. They can also receive unsubsidized loans from *Rabobank, HSBC*, and smaller local banks or trade credit (loans provided in return for a pre-specified amount of soy) from the numerous grain traders, resellers, and manufacturers in the region. In contrast, most Santarém producers rely almost entirely on Cargill and the local input resellers for credit. Access to subsidized government credit sources through the *Bank of Brazil* or *Bank of the Amazon* is very limited for soybean production, although it is available for other crops. While it is technically possible for producers to obtain funding from lending establishments that are not physically present in the region or utilize the resources of family members residing in other regions, none of the producers we interviewed in Santarém were able to access credit from private sources outside of the region.

The two regions also have markedly different environmental and land tenure institutions. Firstly, Santarém has a different ecological biome designation than Sorriso, even though they both fall within the legal Amazon political boundary. Santarém is located in the Amazon biome, while Sorriso is mainly located in the

Table 1
Supply chain configurations, environmental institutions, land tenure conditions, and background of farmers in Sorriso and Santarém. Data gathered from interviews and secondary sources.

Variable	Sorriso	Santarém
Farms (#)	800	200
Total soy area (ha)	590,000	28,500
Soy traders (#)	14	1
Input resellers (#)	>20	4
Fertilizer mixers (#)	1	0
Cooperatives (#)	4	0
Federal banks (#)	1	2
Private banks (#)	2	1
Credit unions (#)	1	0
Biome designation	Mainly Cerrado, some farms in Amazon	Amazon
Legal reserve rule	Conserve 35% in legal reserve	Conserve 80% in legal reserve
CAR required for credit	Only if located in Amazon	Yes
Land tenure	Most producers have full title	Many producers with informal title
Background of farmers	Most farmers came directly from Southern Brazil	Most farmers came from Southern Brazil, but many originally purchased farms in Mato Grosso before moving to Santarém

transitional forest area of the Cerrado biome.[5] As a result, Sorriso and Santarém have different forest reserve requirements on their property under the Forest Code. The code requires landowners in the Amazon to conserve 80% of their property, while landowners in the Cerrado only have to conserve 35%. In some areas of Santarém that fall within the Economic and Ecological Zoning Plan (ZEE), producers only have to conserve 50% of their property in a legal reserve (Coudel et al., 2012). Producers within the Amazon biome are also subject to the rules of the Soybean Moratorium if they want to sell their grain to any of the major multinational grain traders that are signatories to the Moratorium or obtain subsidized government credit. The Soybean Moratorium rules specify that farmers cannot produce soy on land deforested after 2006 (ABIOVE, 2010). Another rule imposed on farmers in the Amazon biome is that they must have a document called the Rural Environmental Registry (CAR), which outlines property boundaries and demonstrates compliance or plans for compliance with the Forest Code, to obtain credit from the government banks (Banco do Brasil, 1995; Brasil, 2010).

Secondly, due to the fact that Santarém was originally colonized through government relocation programs, many famers in Santarém whose properties are within 100 km of the BR-163 highway still lack full legal title to their land. Without title, loans for producers are restricted to the production potential of the land, rather than the value of the land itself. One area where the two regions do not differ, however, is in the cultural background of the producers operating the soybean farms. A majority of farmers in both regions originally came from Southern Brazil (Parana, Rio Grande do Sul, or Santa Catarina), although many producers in Santarém stopped in Mato Grosso for a few years before moving up to Santarém in the hopes of finding cheaper land and higher soy prices.

The stark differences in environmental and land tenure institutions in Sorriso and Santarém (summarized in Table 1) influence how many hectares producers can plant with soy and how much credit they can access to invest in new technologies. The land use and tenure rules in Santarém increase the transaction costs of doing business in that municipality and create disincentives for new businesses and farmers to move there.

[5] Although a small part of the county is located in the Amazon biome.

Relationship between agglomeration economies and soybean production

Sorriso farmers appear to have greater access to information than farmers in Santarém through a wider variety of producer groups. The Sorriso producers' syndicate holds weekly seminars to exchange information about agricultural technologies and prices and represents producers' interests in various agricultural policy fora. The Mato Grosso Association of Soy Producers (Aprosoja) provides Sorriso producers' with daily text messages about local soy price offerings and promotes the research and use of conventional soy cultivars in the region. Some producers in Sorriso also work with the NGO *Club Amigos da Terra* (CAT) to adopt no-till agriculture and integrated crops and livestock systems, or with the NGO *Aliança da Terra* to adopt best agronomic and operational practices to minimize their environmental impact.

The land and labor markets in Sorriso are far more competitive than that of Santarém. In 2011, farm prices were nearly 5 times higher in Sorriso than Santarém and wages were roughly 2 times higher in Sorriso (Table 2). Sorriso producers had slightly lower fertilizer costs than producers in Santarém and substantially lower lime costs, which may be due a combination of lower transportation costs and greater competition between input providers for customers. However, soy prices were substantially higher in Santarém than Sorriso, likely due to differences in transportation costs and the time of harvest in each region (Fig. 5).[6] Within Sorriso, producers who sold their grain through one of the most well organized cooperatives, *COACEN*, obtained significantly higher soy prices than other producers. Producers also reported lower interest rates on private agricultural loans (including trade credit) in Sorriso than Santarém, possibly due to greater number of credit providers in Sorriso, but public loans had similar rates depending on the farmer's income group. Interest rates in Santarém may also be influenced by stricter federal lending conditions for crop production and land tenure problems in that county.

Sorriso farmers have higher levels of adoption of no-till agriculture and precision fertilizer techniques than Santarém farmers (Table 2). Sorriso producers also have a higher adoption of transgenic technology because they are allowed to sell both conventional and transgenic soy, while Santarém producers are not. As a result, Sorriso producers have a higher diversity of soy cultivars to choose from and receive a premium of $16 per ton for conventional soy. Santarém producers do not have this opportunity.

Santarém producers are subject to different environmental governance conditions than Sorriso producers. In Santarém, representatives from the *Nature Conservancy* (TNC) have partnered with Cargill to visit soy farms in every year to make sure farmers are complying with the Soybean moratorium and Forest Code rules. In Sorriso, producers can hypothetically avoid providing evidence of their compliance with the Forest Code so long as they do not require credit from the Federal Government.

[6] International soy prices fluctuate greatly during the year according to seasonal differences in world supply relative to demand. Producers in the North America tend to harvest their soy around September–October, while a majority of the soy producers in the South America harvest between January–June, depending on their proximity to the equator. Prices tend to be lowest while US farmers are harvesting, because supply is at its greatest level relative to demand during these months. Few producers in Sorriso market their grain while US producers are harvesting due to the low prices, but many producers in Santarém are forced to sell a portion of their harvest during this period because they need credit to purchase inputs for the upcoming growing season.

Table 2
Differences in individual supply chain arrangements and soybean production between cases. Data gathered from survey. Mean values from each case and result of *t*-test for significant differences between samples.

Category	Variable	Sorriso (n = 41)	Santarém (n = 32)	Signif.
		Mean		
Output	Av. farm soy planted area (ha)	2954.0	434.0	0.00
	Av. farm soy yield 2011 (MT/ha)	3.7	2.8	0.00
Supply chain arrangement	Member any COOP (% of producers)	59.0	10.0	0.00
	Buy inputs from COOP (% of producers)	36.0	0.0	0.00
	Buy inputs from reseller (% of producers)	41.0	97.0	0.00
	Own/work at input store (% of producers)	33.0	3.0	0.00
	Sell through COOP (% of producers)	41.0	0.0	0.00
	Sell to trader (% of producers)	78.0	100.0	0.04
	Use credit for production (% of producers)	80.0	87.0	0.45
	Gov. credit (% of producers)	62.0	61.0	0.86
	Trade credit (% of producers)	18.0	63.0	0.00
	Private credit (% of producers)	10.0	0.0	0.00
	Credit level (US$/ha)	300.0	359.0	0.46
Inputs	Nitrogen (kg/ha)	0.8	4.0	0.02
	Phosphorus (kg/ha)	87.0	64.0	0.00
	Potassium (kg/ha)	90.0	76.0	0.00
	Lime (MT/ha)	0.9	2.3	0.00
	Labor (full-time/100 ha)	0.6	1.0	0.00
Technology	Direct plant/no-till (% of area)	100.0	30.0	0.00
	Precision fertilizer (% of producers)	66.0	0.0	0.00
	Use any GM (% of producers)	98.0	0.0	0.00
	GM area (% of total planted area)	84.0	0.0	0.00
Prices,[a] Profit	Cost P (US$/kg)	2.7	3.6	0.00
	Cost K (US$/kg)	2.6	2.6	0.82
	Cost lime (US$/ton)	56.0	97.0	0.00
	Cost labor US$/month	1450.0	771.0	0.00
	Land[b] sell price (US$/ha)	10,769.0	2497.0	0.00
	Land rent price (US$/ha)	222.0	125.0	0.00
	Interest rate gov. program (%/Yr)	6.8	6.1	–
	Interest rate trade credit (%/Yr)	12.6	18.2	–
	Interest rate private bank (%/Yr)	13.0	NA	–
	Variable cost per hectare (US$/ha)	737.0	567.0	0.03
	Total cost per hectare[c] (US$/ha)	870.0	916.0	0.19
	Average soy price (US$/MT)	351.0	456.0	0.00
	Revenues (US$/ha)	1304.0	1304.0	0.98
	Profit margin (US$/ha)	435.0	394.0	0.45

[a] All prices have been converted to US dollars using the appropriate exchange rate for that month.
[b] Land that is technically suitable for soy and legally available for cultivation given existing land use rules.
[c] Depreciation and costs of land are not included.

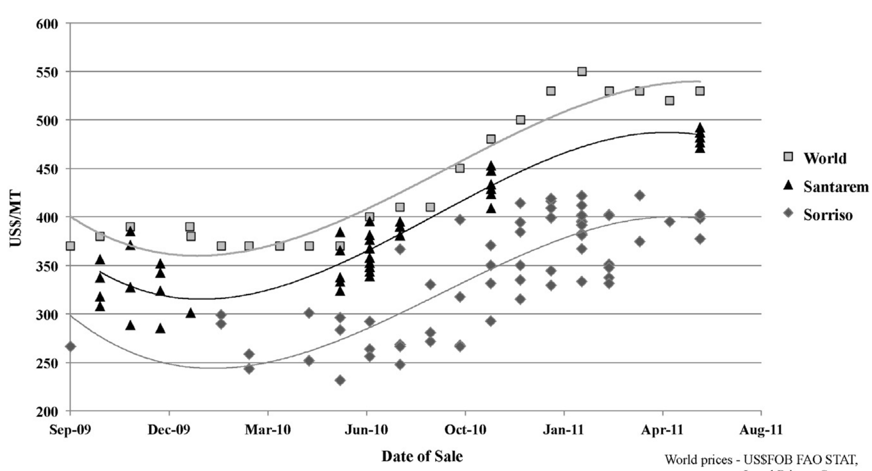

Fig. 5. Soy prices received by producers for spot and forward sales in case regions versus monthly US$FOB prices. Polynomial trendlines added.

Discussion

The theory presented in the first part of this article suggests that the transportation infrastructure, biophysical conditions, and environmental institutions in a region can stimulate or prevent the concentration and diversification of supply chain actors in a region (i.e., the development of agglomeration economies). We posited that when agglomeration economies occur they create positive externalities related to prices, information, access to resources, and land use rules, which increases the local profitability of agriculture. We also hypothesized that higher profits encourage additional supply chain development in the region until land or labor scarcity outweighs gains from agglomeration. Since an increase in the profitability of agricultural production in one region relative to surrounding areas directly influences the location of agricultural expansion and land cover change, this mechanism can result in non-linear land use outcomes, such as exponential growth in some agricultural areas relative to others.

The existing literature (Jepson, 2006b; Rausch, 2013) shows that pioneering producers and supply chain actors initially invested in Sorriso and nearby areas in Mato Grosso due to the suitability of the topography and biophysical conditions and low land prices. Our research adds to this understanding of the colonization process by providing evidence that the development of a more diverse and competitive supply chain in Sorriso (i.e., the creation of a soybean cluster) acted to amplify innovation and productivity in the region, further increasing total factor productivity relative to other areas. The positive feedback loop between superior biophysical advantages and supply chain agglomeration then led to rapid soybean investment in the region and the widespread conversion of land to soybean production.

It is also possible that strength of the supply chain in Sorriso and other counties in the legal Amazon region of Mato Grosso (versus the Amazon biome region) helped the region avoid stronger land use regulations relative to counties further north in Mato Grosso and Pará. One way this could occur is through official lobbying channels, since areas where there are more farmers and agribusinesses operating should be able to spend more money on lobbying (and thus have a greater voice in a political process) than areas where there are few producers and businesses. Another possibility is that regulators and stakeholders in the negotiations for the soybean moratorium chose not to include portions of the legal Amazon outside of the Amazon biome in the moratorium because the opportunity costs of introducing new regulations in that region were higher. Either way there is a potential link between the level of agglomeration that has occurred in a region and the creation of rules regulating activities in that region.

In Santarém we saw a very different story. Despite suitable biophysical conditions, the development of the soybean production in the area has been very limited. Traditional Thunian theory, and its focus on the role of transportation costs in determining land use, helps explain why other forms of agriculture (such as fruit, pepper, rice, and bean production) were adopted in region prior to the establishment of a high capacity soybean export terminal in 2003. However, Thunian theory does not explain why soybean production did not expand rapidly in the area after soybean port was established.

The agglomeration economy framework we present above suggests that environmental institutions and land tenure conditions prevented a positive feedback loop in soybean investment in Santarém, leading to a better protection of forests. Rules limiting area expansion through deforestation (Forest Code, Soy Moratorium) and access to capital (Federal credit rules, Soy Moratorium, and land tenure insecurity) have reduced producers' ability to invest in cropland expansion into forests, increased transaction costs, and reduced the potential for economies of scale. These environmental and credit restrictions, combined with negative media attention around soybean production in the Amazon, also created disincentives for agribusinesses at other levels of the supply chain (manufacturers, traders, and credit providers) to invest in the area and disincentives for the government to focus credit lines or technical assistance in Santarém. Involvement by TNC and other international environmental NGOs acted to amplify the costs imposed by these environmental and credit restrictions by helping to ensure their enforcement.

The lack of investment by supply chain actors after the initial construction of the soybean terminal in Santarém resulted in a low level of agribusiness diversity and competition. This stagnation of the supply chain slowed agricultural development in the region and ultimately contributed to the conservation of a larger fraction of native vegetation compared to Sorriso. Furthermore, the lack of investment by more grain traders resulted in a monopoly by Cargill, which allowed for a unique environmental enforcement opportunity. With Cargill as the only major buyer, the supply chain remained extremely transparent. Nearly all soy produced in the region must pass through Cargill, who works closes with TNC to monitor the soy properties for new deforestation and help farmers work toward complying with Forest Code rules. In sum, while public environmental regulations likely affected the emergence of agglomeration economies in Santarém, the organization of the supply chain in that municipality influenced the enforcement of environmental regulations through the type of actors being involved and their sustainability commitments.

Conclusion

The objective of this study was to better understand the development of industrial agricultural frontiers in Brazil using the concept of agglomeration economies from new economic geography. We found that differences in environmental and land tenure institutions influenced the development of agglomeration economies in two counties, which in turn affected the total factor productivity of soy in each region. In particular, the supply chain became extremely competitive and diverse in Sorriso where there were few environmental regulations, while strong environmental restrictions in Santarém stunted the diversification of the supply chain. The development of a soy agglomeration economy in Sorriso increased innovation and total factor productivity in the region and led to extremely rapid soy expansion in that county, while the environmental regulations and monopolistic supply chain in Santarém reduced producers access to land and capital and allowed for unique conservation opportunities.

When the pavement of BR-163 highway connecting Sorriso and Santarém will be completed, freight costs in Sorriso will be reduced by more than $100 per ton (Vera Diaz et al., 2009), substantially increasing soybean prices in Northern Mato Grosso, since transportation costs are frequently born by the grain traders in the Brazilian soy market. Increasing soy prices in Sorriso could drastically increase per hectare profits in the area, further increasing Sorriso's competitive advantage versus other soy suitable areas. However, pavement of the BR-163 could also impel soy agribusinesses to invest in areas in Southern Pará all the way up to Santarém, leading to a diversification of the supply chain in that region and the development of agglomeration economies for soybean production further north in the BR-163 corridor.

Whether or not this investment occurs will depend heavily on the government's choice of environmental institutions to manage agricultural production and conservation in the region and on the soy traders continued adoption of the soybean moratorium. If environmental institutions continue to disincentivize agribusiness investment in the Amazon biome, then soybean profits in the region may remain low relative to areas located in soy agglomeration economies, dampening incentives for soybean expansion and intensification in those areas. While reduced soybean supply chain investment in the Amazon could potentially conflict with regional economic development goals, it could also make environmental governance in the Amazon easier by amplifying disincentives for farmers to expand soybean production.

It is clear from this analysis that future predictive land use and development models of the Amazon should incorporate potential non-linear rent dynamics caused by agglomeration economies in industrial agriculture. Beyond the Amazon, better analysis of the causes and consequences of agglomeration economies in the agricultural sector can help policy makers and land use planners to identify opportunities for agricultural development. In places where supply chain development and agricultural growth have been stagnant, policy makers could focus more effort on changing land use institutions and economic policy to encourage agribusiness investment, instead of individual supports to farmers, since these investments can lead to a positive feedback loop in agricultural productivity and profitability. Targeted supply chain investments in areas with suitable transportation costs and biophysical conditions could increase the flow of information to farmers, stimulate research and development, and lead to rapid innovation in farming methods.

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