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Title: Rents, actors, and the expansion of commodity frontiers in the Gran Chaco

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Abstract

Theories of frontier expansion in the last four decades have been mostly shaped by studies of state-driven smallholder colonization. Modern-day agricultural frontiers, however, are increasingly driven by capitalized corporate agriculture operating with little direct government intervention. The expansion of contemporary frontiers has been explained by the existence of spatially heterogeneous "abnormal" rents, which can be caused by cheap land and labor, technological innovation, lack of regulations, and a variety of other incentives. Here, we argue that understanding the dynamics of these frontiers requires considering the differential ability of actors to capture such rents, which depends on their access to production factors and their information, preferences, and agency.

We propose a new conceptual framework drawing on neo-classical economics and political economy, which we apply to the South American Gran Chaco, a hotspot of deforestation for soy and cattle production. We divide the region into a set of distinct frontiers based on satellite data, field interviews, and expert knowledge, to review the drivers and actors of agricultural expansion in these frontiers. We show that frontier expansion in the Chaco responded to the rents created by new agricultural technologies, infrastructure, and rising producer prices, but that the frontier dynamics were strongly influenced by actors' ability to capture or influence these rents. Our findings thus highlight that understanding contemporary commodity frontiers requires analyzing the novel ways by which the agency of particular groups of actors shapes land-use outcomes.

Keywords: frontiers; rent; Gran Chaco; soy; cattle

Introduction

Humans have always sought to appropriate natural resources, and have done so in part by expanding agriculture through agricultural frontiers, characterized by "the initial existence of abundant land, mostly unoccupied, and by a substantial migration of capital and people" (di Tella 1982). Historically, tropical agricultural frontiers operated through a reallocation of smallholders to marginal areas, driven by a combination of population increase and land scarcity in their areas of origin (Carr 2004; Carr, Lopez, and Bilsborrow 2010), depletion of natural resources, conflicts, and mining booms, and often initiated or supported by states (Rindfuss et al. 2007; Rudel 2007; De Koninck 2000).

Several theories have sought to explain such smallholder frontiers (Browder et al. 2008; Walker et al. 2009; Godar, Tizado, Pokorny, and Johnson 2012). The capitalist penetration thesis posits that frontiers correspond to the progressive spread of capitalist relations of production into ''non-capitalist'' environments. The inter-sectoral articulation thesis analyses how capital accumulation in the secondary and tertiary sectors builds on the captive labor force of smallholders (Browder et al. 2008). Chayanovian models explain frontier land-use change as a dynamic aggregation of household-level economic and demographic processes (Caldas et al. 2007).

These theories generally describe frontiers as moving from a populist or pioneer stage, dominated by smallholders, towards a capitalized or consolidated stage, where more powerful actors consolidate land into large holdings (Foley et al. 2005; Pacheco 2005). This transition can be driven by the low profitability of pioneer agriculture (e.g., due to soil degradation, poor soil quality, lack of technical and financial support), leading to the formation of a "hollow frontier" (Casetti and Gauthier 1977; Hecht 2005), or by a "technology treadmill", where continuing competition leads to intensification and the exclusion of laggards (Levins and Cochrane 2010; Chatalova, Müller, Valentinov, and Balmann 2016). Depending on the

contexts, smallholders may sell their land or be expelled, and either migrate to urban areas or seek cheaper land elsewhere, thereby driving further frontier expansion (Richards 2015, 2012).

In modern frontiers, however, the role of corporate capital and commodity agriculture changes from an indirect cause of frontier expansion through the consolidation of frontiers initially opened up by smallholder pioneers, to its main direct cause (Rudel 2007). This has led some authors to refer to corporatist frontiers, in contrast to smallholder frontiers (Browder and Godfrey 1997), although this distinction is not always clear-cut (Pacheco 2012), and some contemporary frontiers can be driven by both types of farmers (Barbier 2012). Governments, meanwhile, have shifted from a role of planning to one of facilitation (Rudel 2007), or of non-intervention. The combination of corporate actors and the relative absence of state planning gives rise to so-called neoliberal frontiers (Brannstrom 2009; Hecht 2005). In this paper, we define commodity frontiers as areas where the production of agricultural commodities (such as beef, soy, or palm oil) by large-scale farms expands over other land uses, and whose development is shaped by the greater ability of these large-scale actors to influence and capture agricultural rents. In that sense, the concept of commodity frontier overlaps with, but is distinct from, that of neoliberal frontier. While the latter is defined by a neoliberal political environment, commodity frontiers have continued to exist in a "post-neoliberal" era (Grugel and Riggirozzi 2012). The concept of commodity frontiers also puts greater emphasis on the agency of large farms, in addition to that of states and meso-level organizations (Jepson 2006).

The expansion of commodity frontiers is premised on the existence of an "abnormal" rent, i.e. an economic rent that exceeds the bid rent or land price, generated by factors such as cheap (or forced) labor, technological innovation, or legal and economic incentives (Barbier 2012; di Tella 1982). As long as this extraordinary rent exists, new actors move in to exploit it, driving frontier expansion. Not all actors, however, have equal access to this rent, and differences in their ability to capture it determine whether and when they move in. In state-driven frontiers,

which are often motivated by geopolitical and other motives rather than by potential rents, these differences are often dampened by targeted policies and support for actors with lower capacity. In the absence of such safeguards, the presence of highly capitalized actors creates larger differentials between actors. We argue that these differentials have the potential to shape land-use and social outcomes more than they would in smallholder frontiers. To understand the dynamics of contemporary commodity frontiers, it is therefore important to consider not only the causes that increase economic rents, but also the role and characteristics of heterogeneous actors, and their capacity to shape and capture those rents.

The objective of this paper is to analyze how the interactions between structural mechanisms that create rents and the capabilities of heterogeneous agents influence the development of commodity frontiers, using the case of the Gran Chaco (Figure 1), a dry woodland ecoregion extending between Northern Argentina, Western Paraguay and South-Eastern Bolivia, and one of the most active deforestation frontiers of the world (Baumann et al. 2016). Based on a review of the causes and agents of frontier expansion in the Gran Chaco, we show that the interaction of rents and agentic capabilities can play out in various ways, but that there are key common processes in these frontiers. We start by laying out the foundations of our theoretical framework; then, we provide a short comparative history of the different commodity frontiers of the Gran Chaco. Finally, we discuss the ways in which the integration of actor heterogeneity helps improve our understanding of frontier expansion processes.

Theoretical framework

Agricultural frontiers are characterized by an abundance of "unoccupied" land, i.e., land not yet under permanent cultivation (di Tella 1982). At equilibrium, whether land is cultivated or not depends on the economic rent of agricultural vs. non-agricultural land uses, reflected in the bid rent that users are willing to pay for land, which itself determines land prices (Walker

2004). Following von Thünen, this rent decreases with distance to agricultural markets, and the transition between cultivated and uncultivated land happens where the rent of the former is lower than that of the latter ((Angelsen 2010); Figure 2A). This border moves as the factors influencing rents, e.g., transport and input costs or commodity prices, change. Gradual changes in the rent factors, however, do not satisfactorily explain the rapid expansion of commodity frontiers. For a commodity frontier to emerge, free or cheap uncultivated land must suddenly acquire potential value for at least some actors through an abnormal rent (di Tella, 1982, p.212), (Figure 2B). The expectation of such an exceptional rent, founded or speculative, drives investments at the frontier until the bid rent catches up with the economic rent (Figure 2C).

Five main mechanisms may induce a sudden increase in the economic rent in commodity frontiers. First, a change in accessibility, typically through the construction of roads and railways, improvements in waterways, and new storage or processing facilities, will diminish production costs and increase rents (Angelsen 2010). Second, a change in land productivity, due to changing agro-environmental conditions (e.g., increasing rainfall or temperatures, or wetland drainage), can increase the output-to-input ratio. Third, rent can increase through technological innovations such as improvement in cultivation techniques, seed technology, or machinery (Kaimowitz and Smith 2001; Angelsen and Kaimowitz 2001). Fourth, producer prices and/or demand may change abruptly, for example when export restrictions are lifted (e.g., when a region becomes foot-and-mouth disease-free, see (Schierhorn et al. 2016)), raising producer prices or allowing farmers to sell more at the same price. Finally, subsidies or other policies such as tax exemptions can directly affect rents by decreasing the cost of inputs such as labor, capital, or energy, or raising producer prices (Hecht 1985; Jepson 2006; Binswanger 1991).

Other processes such as agglomeration economies can support these mechanisms, as clusters of farmers may benefit from the same infrastructures, spread new technologies, or

lobby more effectively for subsidies (Garrett, Lambin, and Naylor 2013b). Abnormal rents will naturally tend towards zero under a perfectly competitive market situation with finite land reserves, as more and more agents exploit them, driving demand for land, and thus land prices, up. However, heterogeneous agents and imperfect markets can temporarily maintain a disequilibrium between bid rent and economic rent, thus creating the conditions for commodity frontiers to emerge.

Recent work on frontiers has examined the complex ways in which frontier expansion is shaped by factors affecting incentives at different scales, but it has tended to overlook the role of agent heterogeneity in frontier formation. For example, building upon rent theory and political economy, Jepson (2006) used an institutional approach to show "how organizations interact with the political economy (cheap credit, development programs, and subsidies) and influence other important cost factors (technology, property rights, and access to markets) to produce the new modern frontier in the South American tropics". Jepson et al. (2010) further developed the role of institutions such as property rights and contracts, and showed that, along with organizations (firms and cooperatives), they "formed a regime of access that mediated social-environmental interaction to create the conditions for […] land-change outcomes". While this work highlights the diversity of institutional forms influencing incentives that produce frontiers, it tends to treat farmers themselves as relatively homogeneous in their response to these incentives.

High rents at the margin are not, however, a sufficient condition for frontier development. If no actor is positioned or willing to act upon them, the frontier will remain unexploited. While in some situations (e.g., at frontiers dominated by small-scale colonists), famers can be treated as relatively homogeneous in their response to rents and their influence on frontier development, this is increasingly inaccurate in contemporary commodity frontiers. We distinguish between four characteristics that differentiate actors' response to an existing rent.

First, they need information on the existence and the amount of the rent. An actor with no information will not invest, and an actor with insufficient information may perceive investments as riskier. Second, access to land and other factors of production (including financial capital) is a necessary condition for production. Third, preferences, particularly risk and time preference, induce different responses for a given rent, risk level and time frame. High rents may be associated with higher risks, deterring risk-averse actors, or they may require a long time to materialize, which may deter actors favoring short-term returns. Finally, actors with greater agency, or power to influence factors that affect agricultural rents, may invest more readily than others, as they can expect some conditions to improve as a result of their actions. Examples include lobbying for legal access or building transport infrastructure (Figure 2D).

The combination of economic rents and heterogeneous actors can explain why the rapid dynamics observed on modern commodity frontiers depart from the gradual expansion predicted by the von Thünen model. At an early stage of commodity frontier expansion, which we call "pre-frontier" after Rodrigues et al. (2009), an economic rent is created for the reasons mentioned above, but in the absence of actors with sufficient access or information to capture it, it does not trigger land-use change or an increase in the bid rent (Figure 2E). During early frontier development, only a limited number of actors are positioned to take advantage of the rent. Initial developments generate agglomeration economies, decreasing costs, and information on the rent spreads, which decreases perceived risk. The area becomes attractive to new actors, and capital flows into the frontier. As this happens, land prices start rising more drastically towards the point of equilibrium, and the abnormal rent decreases, along with the flow of investment. This leads to a post-frontier stage when the abnormal rent disappears, and agricultural expansion returns to being a function of gradual changes in population and land prices.

193 The existence and magnitude of different kinds of rent factors and the presence of certain
194 types of actors, as well as the way their interactions play out in terms of frontier dynamics
195 (Figure 3), depend on local context and history. Cultural factors, historical legacies, ties to
196 global markets, or geographic particularities all shape the development of specific frontiers. In
197 the next section, we review different frontiers in the Gran Chaco, and reexamine their dynamics
198 in the light of our theoretical framework.

199

200 **Frontiers of the Gran Chaco**

201 The Gran Chaco, a dry woodland ecoregion, covers over seventy million hectares in
202 Argentina, Bolivia and Paraguay. In the last decades, the Gran Chaco has experienced among
203 the world's highest deforestation rates, with the conversion of over fourteen million hectares of
204 woodlands to agriculture between 1985 and 2013 (Baumann et al. 2016). The new wealth
205 generated by this expansion has come at a high social and environmental cost. Many of the
206 Gran Chaco's 145 mammal, 400 bird, thirty amphibian and forty-six tree species are threatened
207 (Torres, Gasparri, Blendinger, and Grau 2014), and agricultural expansion has triggered huge
208 carbon emissions (Baumann et al. 2016), and caused the displacement of indigenous
209 populations and other smallholders (e.g., Bessire 2014).

210 Agricultural expansion has occurred along several distinct frontiers. While these share
211 common causal processes and pathways, they also exhibit significant differences, e.g., in the
212 actors involved or the land uses driving expansion. To study these differences and
213 commonalities, we divided the Gran Chaco into twelve frontiers, and reviewed their recent
214 history. This analytical approach is not meant to provide a formal typology of frontier pathways,
215 but rather to facilitate the discussion of local-level dynamics.

We first divided the Gran Chaco (Olson et al. 2001) into hexagons of 10-km diameter, for which we calculated the total area of cropland, pastures, and forests for 1985, 2000 and 2013, using land-cover maps from Bauman et al. (2016). We then divided these hexagons into classes of high (>66 percent), medium (33 to 66 percent) and low (<33 percent) forest cover, and high (>2.5 percent), medium (1-2.5 percent) and low (<1 percent) annual deforestation rates[1] for the periods 1985-2000 and 2000-2013 (Figure 4A). We considered as "active deforestation frontier" (Rodrigues et al. 2009) the hexagons with a combination of high forest cover and high or medium deforestation rates, or medium forest cover and high deforestation rates, assuming a transition from dense forest to low-density forest and agriculture. We considered frontiers as distinct when they expanded from a different geographic origin, based both on the patterns observed in maps and on the authors' knowledge, resulting in the identification of twelve distinct frontiers (seven in Argentina, two in Bolivia, and three in Paraguay; Figure 4C). The number and location of frontiers was robust to variations in the thresholds used to define classes of high, medium and low forest cover and deforestation.

We characterized each frontier based on information on land-use change, sources of rent, and actors involved. Interviews conducted by the first author in 2013, 2014 and 2016 form the basis of our qualitative insights, along with expert knowledge of the other authors, literature, and data from various government and non-government sources. Interviews were conducted with 126 medium- to large-scale farmers and with key informants from agricultural cooperatives and lobbies (29), industry and services (17), research and extension services (22), social and environmental NGOs (29), and government organizations (13, Table 1). We used a snowball sampling procedure. Farmers, contacted through producers' associations or other contacts (e.g., real-estate agents, NGO employees, or researchers), were asked to provide the contacts of other producers they knew. We used key informant interviews to verify that we were not missing important categories of actors. Semi-structured interviews with farmers included

241 questions about production history and methods, past land investments, and other
242 characteristics such as their relationship to other supply chain actors. Open and semi-structured
243 interviews with key informants covered a wide range of topics, from actors and dynamics of
244 frontier expansion to supply chain structure, social and environmental issues, and governance.
245 Interviews were conducted in Spanish or German (in the Mennonite colonies) and transcribed
246 subsequently. We conducted textual searches through the body of transcribed interviews to
247 generate and cross-check statements on processes and actors of land use change. Wherever
248 possible, we cite independent sources to support our evidence.

249

250 ***Frontiers of Argentina***

251 The pre-frontier Chaco in Argentina long harbored *criollos* (i.e., small-scale pastoralists
252 of European and indigenous descent) and indigenous communities living from subsistence
253 farming and herding, hunting and gathering, and occasional contract work in factories and farms
254 (Miller 2001). While some commodity crops, such as white and black beans, sugar cane, cotton,
255 wheat, sorghum and corn, had encroached timidly into the Gran Chaco in earlier decades
256 (Morello, Pengue, and Rodriguez 2005), frontier expansion took off with the 1990s' soy boom
257 (Grau, Gasparri, and Aide 2005), caused by increasing global demand and rising prices for soy,
258 and the adoption of no-till cropping and genetically modified (GM) soy seeds in the mid-1990s,
259 in the context of a long-term increase in rainfall (Delvenne, Vasen, and Vara 2013; Grau,
260 Gasparri, and Aide 2005; Hoyos et al. 2013; Zak, Cabido, Cáceres, and Díaz 2008). No-till
261 cropping allowed for higher water retention in soils, a key factor in dry environments, and its
262 spread was enabled by the development of Glyphosate-resistant GM soy, which removed the
263 need to till the soil for weed control (Qaim and Traxler 2005). The introduction of storage bags
264 in the mid-1990s also supported expansion into areas without proper storage infrastructure
265 (Goldfarb and van der Haar 2015). Soy cultivation displaced cattle ranching from the Humid

Pampas, a grassland ecoregion of Central Argentina (Figure 1) to the Chaco, and provided soy farmers with surplus capital to reinvest in expansion (Viglizzo et al. 2011). The expansion of cattle ranching was also supported by growing meat demand and improved pasture varieties. In 2001, following the Argentine economic crisis, currency devaluation lowered production costs (mostly borne in pesos) relative to export prices, increasing profits from soy exports (Gasparri and Grau 2009). The government granted farmers the payment in pesos of debts contracted in dollars, which in effect dramatically reduced these debts (Cáceres 2015). In parallel, a loss of trust in the banking system provoked a massive redirection of capital towards agriculture, considered a safer investment. These conditions triggered a second soy boom that led to further expansion in the Argentine Chaco (Gasparri, Grau, and Gutiérrez Angonese 2013).

Argentine frontiers expanded from consolidated agricultural areas in humid regions towards the drier parts of the Chaco. In this process, criollos and indigenous communities were displaced further into the Chaco (Goldfarb and van der Haar 2015), migrated to towns and cities (Sacchi and Gasparri 2015; Vivaldi 2011) or integrated the frontier economy as agricultural workers, e.g., for forest clearing (Paolasso, Krapovickas, and Gasparri 2012). Service providers from the Pampas followed pioneers, some of them buying land and becoming farmers themselves. Multinational corporations progressively replaced local grain traders, and numerous medium-scale pioneer farms, unable to withstand growing competition, were consolidated into larger farms.

The frontiers of Córdoba, Bandera and Chaco-Santiago (1-3 on Figure 4C; Figure 5), separated from each other by a series of vast saline depressions, expanded north- and westwards along a decreasing rainfall gradient (Zak, Cabido, and Hodgson 2004; Gasparri, Grau, and Sacchi 2015; Hoyos et al. 2013). Agricultural expansion in the northeast of Córdoba took off in the mid-1990s when the soy boom displaced cattle ranching from the Pampas and created a sudden abundance of capital that led farmers to seek new investment outlets. Pioneers met

limited resistance from criollo populations, though agricultural expansion was met with fierce opposition from urban civil society (Cáceres 2015). Soy gradually replaced pastures (Table 2, Figure 4B), thanks in part to an increase in rainfall, except in northwest Córdoba where no such increase occurred (Hoyos et al. 2013). In the water-deficient west, recent expansion was caused mostly by selective logging for fuelwood and charcoal production, with some cattle ranching and irrigated cultivation.

Bandera's agricultural development dates back to the arrival in the early 1990s of small-scale farmers, many of them affiliated to an agricultural cooperative in northern Santa Fe (Avellaneda), and some from the Pampas of Córdoba. A wave of larger investors from the Pampas arrived in the 2000s, while transnational commodity traders established offices in the area. Bandera's development follows the same pattern as Córdoba's, with an early expansion as a cattle frontier followed by a soy boom from the mid-1990s on. By the late 2000s, many of the original pioneers had sold or leased their land to larger companies and returned home, for either economic or personal reasons.

Further North, the Chaco-Santiago frontier expanded along roads 16 and 89 into two provinces with markedly different social and political contexts. Santiago del Estero (Figure 1), with large undeveloped properties, ongoing social conflicts, and weak governance, had little agriculture before the soy boom. Chaco province had smaller properties, a stronger rule of law, and a longer legacy of agriculture. A cotton boom in the late 1980s caused a first influx of investment from Buenos Aires and Córdoba to the Chaco province, speeding up deforestation. Following several harvest failures in the mid-1990s, cotton gave way to soy as the primary driver of this agricultural expansion (Abel Gómez 2014). The proximity to booming agricultural clusters in the Chaco province made the large undeveloped properties of Santiago del Estero increasingly attractive, and in the 2000s, more outside investors appeared, many of them from

Córdoba, driving crops and pastures further west into the dry Chaco, and exacerbating existing conflicts (Goldfarb and van der Haar 2015).

Frontiers of Argentina's *Umbral al Chaco* (4-6 in Figure 4C) are characterized by a westward gradient of increasing rainfall due to the presence of the sierras and pre-Andean mountains. Initial agricultural developments occurred in the wetter foothills of Tucumán, Jujuy and Salta for the cultivation of sugar cane, followed by a limited expansion north- and eastwards of white and black bean cultivation in the 1970s, after all land suitable for sugar cane had been settled. Faster expansion into the Chaco, east of the main north-south road axis (roads 5 and 34), is more recent, and mostly related to soy cultivation.

Tucumán's agricultural experimentation center, the Estación Experimental Agroindustrial Obispo Colombres, had a pivotal role in the development of new soy varieties in Argentina. By 1985, Tucumán's frontier had already extended to towns in the South of Salta province (Metán, Rosario de la Frontera), and sugar cane had colonized all areas with sufficient rainfall. In the 1990s, eastward expansion beyond these areas was driven by local sugar cane farmers diversifying into soy and cattle production, and by the displacement of cattle by soy farming. In the 2000s, more farmers bought and developed land across provincial borders, particularly in western Santiago del Estero following the pavement of road 34 in 2005, but also in Catamarca and Salta. Unlike farmers from Córdoba or Buenos Aires, they mostly favored areas close to Tucumán, and few jumped to other frontiers.

Anta's development beyond the wetter foothills took off in the 1980s with early forest clearings for cattle ranching and bean production by family companies from Salta, Jujuy and Buenos Aires. With the first soy boom, expansion quickened and new actors appeared, notably foreign companies which, although not numerous, acquired large quantities of land. Anta had very large properties of up to tens of thousands of hectares, favoring large investments, and a powerful landed elite, mostly from Salta. Towards the end of the 2000s, expansion was almost

exclusively driven by cattle ranching, as most of the land suitable for cultivation was already in use.

The agricultural frontier in Tartagal is an eastward extension of the colonization of the moist Yunga forests in the Andean foothills during the 1980s and 1990s (Brown and Malizia 2004), facilitated by a network of trails left by petroleum exploration (Morello 2005). The area has been an important producer of beans in addition to soy and cattle, and croplands, rather than pastures, remain the primary driver of expansion (Figures 4B & 5, Table 2). Bound by the Bermejo and Pilcomayo rivers, the region has strong indigenous and criollo presence, which has led to the majority of the area being designated as a zone of restricted agricultural development under the 2007 forest law (*ley de bosques*, law 26,331).

Finally, Formosa is the most recent agricultural frontier in the Argentine Chaco, expanding alongside road 81 and limited to the north by the Río Pilcomayo, and to the south by the Río Bermejo. Long ignored by industrial agriculture because of its uneven soil quality, its inaccessibility, the prevalence of diseases, and the high flood risk, it became more attractive in the late 2000s as land elsewhere was getting scarcer and the completion of road 81 (in 2009) improved accessibility. Experiments with improved pastures, conducted in the 1990s and 2000s by the Centro de Validación de Tecnologías Agropecuarias (CEDEVA), and laxer environmental regulations than in neighboring provinces, may have incentivized expansion (le Polain de Waroux, Garrett, Heilmayr, and Lambin 2016). Almost exclusively a cattle frontier (Figure 4B & 5, Table 2), Formosa was developed by farmers from the Córdoba, Buenos Aires, and to a lesser extent, Chaco provinces. Holding the largest indigenous population in the country, the area has similar social conflicts to the Tartagal and Chaco-Santiago frontiers, but with lower visibility and less legal protection, even though land titles were delivered relatively early to indigenous communities.

365 ***Frontiers of Bolivia***

366 The Santa Cruz lowlands, traditionally a sugar cane production area, extend eastwards
367 from the pre-Andes in a triangle of highly fertile alluvial land with moderate rainfall, limited to
368 the north by more humid areas, to the east by the infertile Brazilian shield, and to the south and
369 southeast by decreasing rainfall[2] (Müller, Müller, Schierhorn, Gerold, et al. 2011). Starting in
370 1985, structural adjustment led to currency devaluation, reduced tariffs and suppression of price
371 controls, preferential access to Andean markets, and liberalization of land markets (Kaimowitz,
372 Thiele, and Pacheco 1999; Pacheco 2006). These changes, along with extremely cheap land
373 (Zoomers 2003); abundant private capital from the coca, timber and gas industries and from
374 Brazilian investors (Kaimowitz, Thiele, and Pacheco 1999; Hecht 2005); new transport and
375 storage infrastructure (Pacheco 2006); and improved agricultural technologies, including no-
376 till cropping and new soy and grass varieties (Pérez Luna 2007), unleashed an era of rapid
377 deforestation, which the 1996 agrarian reform further incentivized by making land rights
378 conditional on productive use (Redo, Millington, and Hindery 2011).

379 A first phase of soy expansion in the early 1990's was largely driven by farmers from
380 Mato Grosso do Sul and Paraná (Figure 1) fleeing extreme inflation in Brazil. Mennonite
381 colonies also opened up new areas, albeit with a different model, based on clusters of small-
382 scale properties under intensive use in isolated locations. Bolivian farmers were less involved,
383 and while some thrived, many ended up selling or leasing their land (McKay and Colque 2015).
384 In the late 1990s, several consecutive harvest failures, combined with a credit crisis and
385 plummeting global soy prices, drove many farmers out of business. Amidst collapsing land
386 prices, numerous Brazilian farms were acquired by Bolivian companies or claimed by creditors
387 (Killeen et al. 2008). Meanwhile, in the 2000s, Argentine companies, mostly from the Pampas,
388 participated in a second Bolivian soy boom, with a production model based on the outsourcing
389 of services such as spraying or harvesting (Urioste 2012). Cattle ranching dominated expansion

during this second period (Table 2, Figure 5), both because of the aridity and lower fertility of the remaining land, and because of the conversion to pastures of areas no longer suitable for crop cultivation (Müller, Pacheco, and Montero 2014).

The small frontier of the Bolivian Andean Foothills is limited by decreasing rainfall to the east, leaving a narrow strip of suitable land, much of which is protected under the Kaa-Iya National Park and indigenous reserves. As in neighboring Tartagal, petroleum exploration has left a grid of roads that facilitate access. Mennonite colonies have established mixed agricultural production in some areas, and Bolivian ranchers practice extensive cattle ranching (Müller, Larrea-Alcázar, Cuéllar, and Espinoza 2014). Recently, increasing numbers of Santa Cruz ranchers acquired ranchland, benefiting from low land prices, improved pasture varieties and new water storage technology.

Frontiers of Paraguay

The Paraguayan Chaco is characterized by a westward gradient of decreasing rainfall, and limited by the rivers Paraguay and Pilcomayo to the east and southwest, and by sandy soils to the northwest. Indigenous communities have since the 1920s shared this territory with Mennonite colonists from Canada, Russia and Germany. With most of the land in private hands since its distribution to foreign investors after the Triple Alliance war (Vázquez 2013; Caldas, Goodin, Sherwood, Krauer, et al. 2013), extremely cheap land, and a quasi-absence of the State, the Paraguayan Chaco has been a haven for large-scale speculative investments. In the 1990s, research conducted locally on drought-resistant pastures, and new Brazilian deforestation techniques using chains spanned between bulldozers, enabled fast expansion of cattle ranching. In the 2000s, improvements in sanitary conditions, the eradication of foot-and-mouth disease (in 2005, (Reuters 2005)), improved water storage technology, and the construction of new export-grade slaughterhouses and acquisition of older ones by Brazilian companies with tight

links to international markets (Velázquez 2012), supported a boom in beef production for export. Prospects of a highly profitable beef sector, advertised in the 2006 "National Meat Plan" (Brusquetti and Vasconsellos 2006), incentivized national banks endowed with large amounts of capital from the Eastern Paraguayan soy boom to support investments in the Chaco. The 2004 "zero-deforestation law" in Paraguay's Atlantic Forest (law 2,524) may also have displaced some cattle ranching to the Chaco. Finally, Mennonite colonies acted as a service hub for outsiders whom the highly-developed infrastructure and service industry enabled to manage ranches remotely. The development of the Paraguayan Chaco led to important social and demographic changes, with indigenous populations being pushed into settlements (Bessire 2014), and contract workers form Eastern Paraguay and Brazil progressively outnumbering Mennonites in the colonies.

The development of Paraguay's Central Chaco frontier (Figure 4C, 10) started in the first half of the 20th century with the first Mennonite settlements (Loma Plata in 1927, Filadelfia in 1930). The expansion of pastures around the colonies was quickened by the introduction of new tropical grasses, such as *Panicum maximum,* in the mid-1980s, and the commercial success of milk production, leading to the acquisition by Mennonite cooperatives of large properties for planned colonization. In the 2000s, Mennonites also increasingly managed foreign-owned farms. The cooperatives maintained roads and built their own slaughterhouses in the Central Chaco and close to Asunción.

The Paraguayan Semiarid Chaco (Figure 4C, 11), close to the Mennonite colonies, but removed from their early developments, experienced an influx of investments by French and German companies in the 1980s (Vázquez, 2013; p.154). Following the expansion of the Central Chaco frontier, numerous national and foreign companies started investing in the area, which enjoyed the proximity to the colonies' infrastructure, but with lower land prices. In the late 2000s, an Argentine company was starting to experiment with large-scale soy production.

Finally, the Chaco-Pantanal frontier (Figure 4C, 12), a region with very fertile soils and high rainfall, was initiated in the late 1990s by large-scale ranchers from the Brazilian states of Mato Grosso do Sul and São Paulo (Figure 1), who took advantage of the area's proximity to Brazil and the Mennonite colonies. In the 2000s, Eastern Paraguayan cattle ranchers followed their lead, as did many non-agricultural companies. In the late 2000s, as Argentinians flooded the Uruguayan land market (Piñeiro 2012), increasing numbers of Uruguayan investors (González 2013), and by 2016, also a few Argentine companies, appeared. The Korean Reverend Sun Myung Moon's Unification Church also purchased 600,000 ha of land in 2000 through its company "La Victoria" (Vázquez 2013).

Rents, actors, and frontier expansion in the Gran Chaco

Causes of high agricultural rents

While there is no quantitative data on the value of economic rents, statements from our interviews provide ample anecdotal evidence that they far exceeded the low land prices in early frontiers (Figure 5), e.g., "there wasn't land of such fertility for such ridiculously low prices anywhere else in the world", (interview with a Uruguayan cattle rancher in the Chaco-Pantanal frontier, 10/21/2013), or "in 3, 4 years, you recoup your investment — that's why we're here" (interview with an Argentine farmer in the Santa Cruz frontier, 08/04/2013). Technological innovation was arguably the major source of such rents in the Gran Chaco (Table 2). GM soy and no-till cropping enabled expansion in Argentina and Bolivia, and new pasture varieties were essential to the growth of the cattle sector, particularly in Paraguay. Booming soy prices in the late 1990s and mid-2000s, combined with currency devaluation, strongly incentivized soy expansion, since soy was sold in dollars but most production costs were paid in local currencies. A boom in Paraguayan beef exports significantly raised producer prices. Apart from cheap loans for Bolivian agriculture in the late 1980s, there were few direct subsidies to

agriculture, although macro-economic policies such as currency devaluation, the suppression of export taxes and reduction of tariffs in Bolivia after 1985, or the repayment in pesos of dollar debts in Argentina after 2001, can be regarded as indirect subsidies. Thus, even in the "neoliberal" era, the State played an important role in generating rents through tax and monetary policies. While increased rainfall and improved accessibility were crucial to expansion, these changes were mostly gradual, and in the case of roads, often endogenous to expansion, and they acted as predisposing factors, rather than triggers, for development.

Actors and their characteristics

Economic rents driving frontier expansion are sustained when forces of friction, determined by the differential ability of actors to capture these rents, prevent land prices from catching up. Here we propose a typology of actors, followed by a discussion of the role of differences in access, information, preferences and agency in generating these frictions.

Commodity producers, the principal direct agents of frontier expansion, can be divided into three categories. *Established farmers* are farmers from an earlier wave of expansion who produce commodity crops in or near the frontier, e.g., Bolivian farmers in Santa Cruz before the soy boom, Mennonite ranchers in Central Chaco, or small-scale farmers in Chaco-Santiago. They have access to land and information on local conditions, but are often constrained in other aspects, e.g., a lack of financial or technological capital and access to market information, or unfavorable preferences (e.g. risk aversion). *Pioneers* are farmers from other regions who move to a frontier at early stages, such as the farmers from Córdoba in Chaco-Santiago, or Brazilian ranchers in Chaco-Pantanal. Their higher risk-tolerance enables them to "activate" frontiers in information-poor environments by bringing financial, technical and social capital to marginal areas. The more risk-averse *latecomers* appear when uncertainty on rents is lower, and

infrastructure better, and tend to focus on the colonization of the "internal" frontier, the forest remnants.

Besides producers, several categories of actors play a less direct, but equally important role in frontier expansion. *Speculators* derive profits from the increase in land prices associated with frontier development. They often overlap with pioneers, arriving when prices are low, and acquiring land that they sell for a premium to latecomers, often after developing it. Their main assets are financial capital and information. *Rentiers* lease land to farmers. They are often established farmers or pioneers outcompeted by newer arrivers. *Service providers* clear land, sow crops, spread herbicides, and harvest, store and transport commodities. Rather than investing in land, they acquire machinery and agricultural inputs, often spearheading the arrival of major service providers and becoming their representatives. *Commodity traders and corporations* buy, process and export commodities, and often also provide inputs and credit to farmers. *Agricultural workers* provide labor for agricultural production. *Smallholders*, including indigenous and criollo populations, live from small-scale farming and herding, hunting, gathering, fishing, charcoal production and contract work. Poor, mostly without land titles, they are generally displaced by frontier development, except where they can secure land titles, as in parts of Bolivia and Argentina, or integrate commodity agriculture as labor. Finally, *government bodies* build roads, set taxes, tariffs and subsidies, allocate land rights, and regulate land use, *research and extension agencies* generate technology and information on local conditions, and *farmers' associations* transfer information through social networks, and lobby governments for changes. Below, we focus on the characteristics of commodity producers, and the ways in which their differences influence their ability to capture and influence rents.

514 ***The role of access***

515 Differential access to land, capital, technology, and production networks, allows some
516 actors to capture rents inaccessible to others. Availability of capital from agriculture or other
517 activities, for example, was common to many pioneers, including farmers from the Pampas
518 investing in the Argentine Chaco, and Brazilian and Uruguayan investors in Paraguay
519 (González 2013). Differential access to credit has also been invoked to explain the success of
520 foreign farmers in Santa Cruz in the 1990s. In the 2000s, in a context of greater credit scarcity,
521 commodity traders came to play an increasingly important role in the financing of farmers, and
522 thus in access to financial capital.

523 Additionally, pioneers often had better access to technological capital and know-how,
524 e.g., Brazilian farmers' advanced agricultural technologies, in part the result of the Brazilian
525 government's investments in agricultural research and development through its Agricultural
526 Research Corporation (Embrapa), or Argentine famers' highly-efficient, service-based
527 management models. In some cases, a combination of local and "imported" know-how enabled
528 farmers to capture rents, e.g., new pastures and cattle breeds developed by Mennonites in
529 Paraguay, and Brazilian ranchers' ability for large-scale management and access to capital and
530 markets. Continuous technological improvement could also function as a "technology
531 treadmill", keeping newcomers out.

532 Access to land for large and foreign farms improved with neoliberal policies in the 1990s,
533 but suffered setbacks under left-wing governments in the 2000s. Land ownership in the
534 Argentine and Paraguayan Chaco was overwhelmingly private (Nolte, le Polain de Waroux,
535 Munger, Reis, et al. 2017). In Bolivia, where public and indigenous ownership dominate, the
536 1990s' neoliberal turn led to the distribution of land titles to large-scale commercial farmers
537 (Pacheco 2006). The government, however, maintained an ambiguous relationship to
538 commercial farming, tolerating a powerful agricultural elite while supporting smallholder

opposition (Colque 2014) and prohibiting land purchases by foreigners (National Constitution, art. 396). Paraguay's 2005 prohibition of foreign land acquisitions in border areas on grounds of national sovereignty (Law 2,532) may have harmed Brazilian agriculture in the Chaco-Pantanal frontier, although land distributed in the context of Paraguay's agrarian reform was hardly regulated (Glauser 2009). Argentina imposed quotas on foreign ownership of land in 2011 (Law 26.737), but this measure did not affect the main actors of land acquisitions in the Chaco, who were nationals.

The "stickiness" of trade relations creates differences in access to production networks, especially for relational value chains (e.g. beef), in which trust and shared norms are an important part of the exchange (Gereffi, Humphrey, and Sturgeon 2005). Small or traditional ranchers in the Chaco often sold to complex chains of local traders catering to regional markets, while large, modern ones often sold to industrialized slaughterhouses that required higher traceability, could handle larger volumes, and catered to international markets. Both transactions involved high levels of trust, but the formalization of norms by large slaughterhouses made it easier for actors able to meet them to gain trust and enter new markets.

Finally, alliances and contracts, formal or not, can facilitate access (W. Jepson, Brannstrom, and Filippi 2010; Garrett, Lambin, and Naylor 2013a). Companies with ties to local or national governments enjoyed preferential access to public lands, often under irregular conditions (e.g., Morini 2011). Local name-bearers for foreign businesses (common in Bolivia and Paraguay), or formal leasing contracts (common in the Argentine Chaco), improved access to land for outsiders. Contracts between absentee landowners and local managers (e.g. Uruguayan companies and Mennonite managers) allowed the former to capture rents without know-how or on-site presence. In the presence of power inequalities and information asymmetries between commercial farmers and smallholders, the formalization of land tenure

563 also secured access to land for the former, facilitating 'land grabs' and the dispossession of
564 smallholders (Goldfarb and van der Haar 2015; Cáceres 2015; de L.T. Oliveira 2013).

565

566 ***The role of information***

567 In the absence of information, potentially lucrative investments at the frontier originally
568 go unnoticed or are considered too risky for most. Chaco pioneers relied on direct observation,
569 hearsay, and comparisons to assess land productivity and climate conditions, and they used
570 knowledge of market, institutional and access conditions to estimate potential rents. Their first
571 experiences generated a limited body of information that decreased uncertainty, and thus
572 perceived risk, for others. The selective transfer of information through social networks
573 participated in the creation of cohorts of farmers following each other's footsteps into new
574 frontiers, while putting outsiders at a disadvantage.

575 Information asymmetries among actors made prospection a crucial activity: pioneers and
576 speculators were always on the lookout for new opportunities, constantly learning about places,
577 market conditions, and potential returns on investments. In the early 2010s, it was common
578 among Chaco farmers to pay prospective visits to other South American countries, or even to
579 Africa. Experienced pioneers could take advantage of their greater knowledge by brokering
580 land deals or managing farms for less-experienced landowners. Respected pioneers created an
581 expectation of high profits that triggered investments by their peers, even if expectations were
582 unmatched by actual rents.

583 As commodity frontiers expanded, access to information became less dependent on
584 specific social ties. Success stories in the media put the new frontiers on the map for the larger
585 public, e.g. the Bolivian lowlands for Brazilians (Klintowitz 1995) and Argentines (Lorenzatti
586 2007), or the Paraguayan Chaco for Uruguayans (Farías 2012). Prominent farmers were equally

important in spreading success narratives (e.g. Muñoz 2015; Artagaveytia 2011), in part with the intention to reap the benefits of land appreciation (through land sales) and agglomeration economies (through lower production costs). Governments too publicized the Chaco for outside investors, e.g., with the Paraguayan National Meat Plan, and extension agencies or farmers' associations frequently provided information to outsiders on local investment conditions. Thus, government institutions contributed to the erosion of information asymmetries, which accelerated expansion, increased competition and contributed to closing the gap between economic and bid rent.

The role of preferences

Farmers' preferences positioned them differently in front of equal potential rents. Risk preference differentiated (risk-tolerant) pioneers from (risk-averse) latecomers. Greater risk tolerance could result from an availability of enough backup capital to withstand failure, especially for large, multi-site companies, or from a lack of options, as for medium-size farmers driven away by competition and divided landholdings. Some companies used investment portfolios to buffer risks, acting as pioneers in some areas and as latecomers in others.

Management styles differed markedly between cohorts of farmers, shaping their attitudes towards specific frontiers. Brazilian farmers often specialized in large-scale investments with full ownership of factors of production, which allowed them to settle in remote places, such as the Chaco-Pantanal frontier, or Santa Cruz in the early 1990s. Argentine farmers tended to outsource most services and were thus more dependent on infrastructure and service providers, which may explain the late development of Formosa. Mennonites, who expanded mostly through the acquisition of land by cooperatives, sought vast expanses of land in remote places for subdivision among their members, though some more entrepreneurial Paraguayan Mennonites started buying land individually in the 2000s. Management preferences also

612 differed between cattle ranchers and soy farmers, the latter being much more dependent on the
613 proximity to agricultural clusters than the former.

614 Cultural and lifestyle preferences mattered, too. For many, being a pioneer implied
615 leaving a familiar cultural context for a more challenging social and physical environment.
616 Familiarity made places "legible" — in Santa Cruz, Brazilians were said to prefer wetter, and
617 Argentines, drier areas, more similar to their respective homes. On the contrary, cultural
618 "otherness" often generated confusion and frustration, to a point that could discourage
619 investors. Farmers from the Pampas, for example, frequently complained about the difficulty
620 of raising a family in the "backwards" towns of the Chaco.

621

622 ***The role of agency***

623 One particularity of commodity frontiers of the Chaco was the ability of certain actors or
624 groups of actors to influence agricultural rents and modify their own access to these rents, e.g.,
625 by building their own roads, investing in technological improvements, lobbying governments
626 for legal access, or capturing different levels in the supply chain. Actors were thus differentiated
627 not only by the rent immediately accessible to them, but also by the rent they could expect to
628 access in the future, given their ability to overcome specific constraints (see Figure 2D).
629 Politically powerful actors, for example, could expect to access land that others could not.
630 Government officials and their allies acquired enormous amounts of land in Anta, the Central
631 Paraguayan Chaco, or Santa Cruz, and large-scale farmers lobbied successfully for the
632 downgrading of zoning plans that limited deforestation in Argentina. Farmers with enough
633 capital also opened their own access roads, or built grain silos, traded inputs and acquired
634 slaughterhouses to capture rents at other levels of the supply chain and improve the profitability
635 of their own activities.

Greater agency was often achieved through alliances, such as farmers' organizations or cooperatives, similarly to the situation in the Brazilian Cerrado (Jepson 2006). Major roads in the Paraguayan Chaco, such as the one linking Mennonite colonies to the Chaco-Pantanal frontier, were built and maintained by consortia of farmers who managed machines and labor, and imposed tolls and use rules. Cooperatives facilitated land acquisition and development by small farmers, as with the Avellaneda cooperative in Bandera, or with Mennonite cooperatives in Paraguay and Bolivia. Other farmers' associations engaged in research, prospection and experimentation in ways that were inaccessible to isolated farmers. Groups of the *Consorcio Regional de Experimentación Agraria* (CREA groups), for example, an organization focused on innovation in agriculture, regularly invited experts from other countries, facilitating technology transfer to their members (Gras and Hernández 2016) (similar to the role of APROSOJA in Brazil (Empinotti 2015)). Finally, medium-sized farmers from the Pampas or Uruguay created consortiums of investors to generate economies of scale — e.g. in the purchase of land and machinery — that made investments in distant Bolivia or Paraguay possible.

Common dynamics of frontier expansion

Despite differences in the causes of rents and the actors driving expansion, frontiers of the Gran Chaco underwent relatively similar trajectories. High rents in early frontier stages were captured by a limited number of actors, usually outsiders with capital (e.g., from the soy boom) and technology (e.g., deforestation techniques), high risk-tolerance, and sufficient agency to alter some of the conditions of production (e.g., accessibility, storing and processing facilities) or political access. Pioneers maintained a competitive advantage through selective information sharing, political exclusion, or technological innovation. Ultimately though, once established, pioneers participated in the diffusion of information in order to fasten expansion and generate speculative benefits and/or agglomeration economies. Land prices boomed as a result (Figure

5), reflecting growing expectations of rents. As agricultural clusters developed, competition for land rose and land prices caught up with rents, ending the disequilibrium.

Taking actor characteristics into consideration in the explanation of frontier dynamics in the Chaco is particularly important at the early stages of frontier development, for three main reasons. First, the ability of certain actors to influence rents makes the emergence of commodity frontiers less predictable based solely on structural factors. Second, mobile actors can embody a link between distant places, allowing for explanations that transcend local drivers. Chaco frontiers were triggered not only by local changes, but also, and especially, by the arrival of new actors responding to changes elsewhere (e.g., sudden capital availability or deteriorating economic conditions). Third, differential access to rents creates the friction necessary to delay a return to equilibrium, generating the nonlinear expansion dynamics observed on commodity frontiers. We argue that selective transfer of information along social networks was an essential mechanism in maintaining these frictions in the Gran Chaco.

Conclusion

Commodity frontiers are expanding into the last remaining undeveloped agricultural land on the planet. While this expansion constitutes a continuation of historical processes, the forms it takes and the actors that drive it are changing. In the 1960s and 1970s, many governments in the Global South directly supported the settlement of frontiers for geopolitical and demographic reasons (Rudel 2007) via colonization plans, land reforms, credit schemes, infrastructure investments, or technological packages. With the 1980s' neoliberal turn in South America, governments largely disengaged from planned settlement, leaving a void that was filled by private actors (and non-governmental organizations, see Brannstrom (2005)), who benefitted from previous infrastructure investments, and from policies generating new rents. Among these were regulation and enforcement of land rights (de L.T. Oliveira 2013), legal protection of

foreign investments (McKay and Colque 2015), legalization of technological innovations such as GM soy, or macro-economic policies, such as the removal of trade barriers and currency devaluation. In the 2000s' "post-neoliberal" era (Grugel and Riggirozzi 2012), the rise of left-wing governments in several South American countries signaled a shift to more ambiguous attitudes towards large-scale farming. The governments of the Kirchners' Argentina, Lula's Brazil, Lugo's Paraguay or Morales's Bolivia acquired legitimacy with their base by adopting policies to defend smallholder and indigenous rights, tax commercial agriculture and curb deforestation and foreign land acquisitions, while continuing to support, or at least tolerate, a powerful agricultural sector on which they depended (Cáceres 2015).

This changing role of the state and the emergence of large-scale commodity farms as major drivers of frontier expansion, while not uniform across the region (see Pacheco (2009)), have consequences for how we conceptualize contemporary frontiers. The Gran Chaco shows how their advance is shaped by the existence of abnormal economic rents and by the presence of actors able to capture these rents. In contrast to a classical view of frontiers, where actors are largely responsive to structural changes often initiated by governments, commodity frontiers of the Gran Chaco were characterized by large differences in the ability of actor groups to capture and influence rents, and to strategically manipulate conditions of access. This differential ability is related to different endowments in terms of information and access to capital, land, technology or markets, which determine their role and position in the process.

Based on our review of frontiers of the Gran Chaco, we propose that dynamics of commodity frontier expansion are characterized by 1) the prevalence of a limited number of actors with the ability to influence rents and access; 2) the mobility of actors across regions and countries, enabling distant causal interactions, including transfers of knowledge and capital; and 3) the importance of the creation and selective transfer of information about agricultural rents in creating and maintaining access differentials. The rent-actor typology proposed here

711 attempts to represent these dynamics by combining agentic and structural explanations of
712 frontier development. As such, it builds upon existing efforts to overcome the limitations of bid
713 rent theory and better represent agent-level and political/institutional dynamics in theories of
714 land-use change (Walker 2004; Jepson 2006; W. E. Jepson, Brannstrom, and Filippi 2010) by
715 incorporating the notions agent-level heterogeneity and disequilibrium as determinants of
716 agricultural expansion. This is important if we are to better anticipate the emergence and
717 development of new commodity frontiers, and the associated social and environmental
718 challenges they might bring.

719 **Notes**

720 1) Calculated as $D = 100 * \frac{1}{t_2 - t_1} * \frac{F_{t_2} - F_{t_1}}{F_{t_1}}$, with F the forest area.

721 2) *Santa Cruz* is only partially in the Chaco ecoregion; its Northern part pertains to the
722 more humid Chiquitano forest.

723

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734 **References**

735 Abel Gómez, C. 2014. Cuestión agraria y emergencia campesina. Las disputas por el acceso a
736 la tierra en la provincia del Chaco, Argentina. *Estudios sociológicos* 30 (89):489–517.

737 Angelsen, A. 2010. Policies for reduced deforestation and their impact on agricultural
738 production. *Proceedings of the National Academy of Sciences of the United States of America*
739 107 (46):19639–19644.

740 Angelsen, A., and D. Kaimowitz eds. 2001. *Agricultural Technologies and Tropical*
741 *Deforestation*. CABI Edition.

742 Artagaveytia, R. 2011. *Paraíso ganadero: Paraguay, tierra de oportunidades*. Estudio 3000.

743 Barbier, E. B. 2012. Scarcity, frontiers and development. *Geographical Journal* 178 (2):110–
744 122.

745 Baumann, M. et al. 2016. Carbon emissions from agricultural expansion and intensification in
746 the Chaco. *Global Change Biology*.

747 Bessire, L. 2014. *Behold the black caiman: A chronicle of Ayoreo life*. University of Chicago
748 Press.

749 Binswanger, H. P. 1991. Brazilian policies that encourage deforestation in the Amazon. *World*
750 *Development* 19 (7):821–829.

751 Brannstrom, C. 2005. Environmental policy reform on north-eastern Brazil's agricultural
752 frontier. *Geoforum* 36:257–271.

753 ———. 2009. South America's neoliberal agricultural frontiers: places of environmental
754 sacrifice or conservation opportunity? *Ambio* 38 (3):141–149.

755 Browder, J. O. et al. 2008. Revisiting Theories of Frontier Expansion in the Brazilian
756 Amazon: A Survey of the Colonist Farming Population in Rondônia's Post-Frontier, 1992-
757 2002. *World Development* 36 (8):1469–1492.

758 Browder, J. O., and B. . Godfrey. 1997. *Rainforest Cities, Urbanization, Development and*
759 *Globalization of the Brazilian Amazon*. New York: Columbia University Press.

760 Brown, A. D., and L. R. Malizia. 2004. Las Selvas Pedemontanas de las Yungas. *Ciencia Hoy*
761 14 (83):52–63.

762 Brusquetti, M. F., and A. Vasconsellos. 2006. *Plan Nacional de la Carne*. Asunción,
763 Paraguay.

764 Cáceres, D. M. 2015. Accumulation by Dispossession and Socio-Environmental Conflicts
765 Caused by the Expansion of Agribusiness in Argentina. *Journal of Agrarian Change* 15
766 (1):116–147.

767 Caldas, M. et al. 2007. Theorizing land cover and land use change: The peasant economy of
768 Amazonian deforestation. *Annals of the Association of American Geographers* 97 (1):86–110.

769 Caldas, M. M., D. Goodin, S. Sherwood, J. M. C. Krauer, et al. 2013. Land Cover Change in
770 the Paraguayan Chaco: 2000-2011. *Journal of Land Use Science* (June
771 2013):130614103019000.

772 Carr, D. L. 2004. Proximate population factors and deforestation in tropical agricultural
773 frontiers. *Population and Environment* 25 (6):585–612.

774 Carr, D. L., A. C. Lopez, and R. E. Bilsborrow. 2010. The population, agriculture, and
775 environment nexus in Latin America: Country-level evidence from the latter half of the

776 twentieth century. *Population and Environment* 30 (6):222–246.

777 Casetti, E., and H. L. Gauthier. 1977. A formalization and test of the "hollow frontier"
778 hypothesis. *Economic Geography* 53 (1):70–78.

779 Chatalova, L., D. Müller, V. Valentinov, and A. Balmann. 2016. The Rise of the Food Risk
780 Society and the Changing Nature of the Technological Treadmill. *Sustainability* 8 (6):1–10.

781 Colque, G. 2014. *Expansión de la frontera agrícola*. La Paz, Bolivia: Fundación Tierra.

782 Delvenne, P., F. Vasen, and A. M. Vara. 2013. The "soy-ization" of Argentina: The dynamics
783 of the "globalized" privatization regime in a peripheral context. *Technology in Society* 35 (2).

784 Empinotti, V. 2015. Beyond the dualities: a nuanced understanding of Brazilian soybean
785 producers. *Food Security* 7 (6):1165–1174. http://dx.doi.org/10.1007/s12571-015-0504-3.

786 Farías, L. 2012. Experiencias exitosas de uruguayos en Paraguay estimulan a nuevos
787 inversores. *El Observador* 1 June. http://www.elobservador.com.uy/experiencias-exitosas-
788 uruguayos-paraguay-estimulan-nuevos-inversores-n225245.

789 Foley, J. a et al. 2005. Global consequences of land use. *Science* 309 (5734):570–574.

790 Garrett, R. D., E. F. Lambin, and R. L. Naylor. 2013a. Land institutions and supply chain
791 configurations as determinants of soybean planted area and yields in Brazil. *Land Use Policy*
792 31:385–396.

793 ———. 2013b. The new economic geography of land use change: Supply chain
794 configurations and land use in the Brazilian Amazon. *Land Use Policy* 34:265–275.

795 Gasparri, N. I., and H. R. Grau. 2009. Deforestation and fragmentation of Chaco dry forest in
796 NW Argentina (1972–2007). *Forest Ecology and Management* 258 (6):913–921.

797 Gasparri, N. I., H. R. Grau, and J. Gutiérrez Angonese. 2013. Linkages between soybean and
798 neotropical deforestation : coupling and transient decoupling dynamics in a multi-decadal
799 analysis. *Global Environmental Change* 23:1605–1614.

800 Gasparri, N. I., H. R. Grau, and L. V. Sacchi. 2015. Determinants of the spatial distribution of
801 cultivated land in the North Argentine Dry Chaco in a multi-decadal study. *Journal of Arid*
802 *Environments* 123:31–39.

803 Gereffi, G., J. Humphrey, and T. Sturgeon. 2005. The governance of global value chains.
804 *Review of International Political Economy* 12 (1):78–104.

805 Glauser, M. 2009. *Extranjerización del Territorio Paraguayo*. Asunción, Paraguay: BASE IS.

806 Godar, J., E. J. Tizado, B. Pokorny, and J. Johnson. 2012. Typology and Characterization of
807 Amazon Colonists: A Case Study Along the Transamazon Highway. *Human Ecology* :1–17.

808 Goldfarb, L., and G. van der Haar. 2015. The moving frontiers of genetically modified soy
809 production: shifts in land control in the Argentinian Chaco. *The Journal of Peasant Studies* 43
810 (2):1–22.

811 González, D. 2013. Uruguayos ya explotan el 12,5% de las tierras ganaderas en Paraguay.
812 *Última Hora* 12 February. http://www.ultimahora.com/uruguayos-ya-explotan-el-125-las-
813 tierras-ganaderas-paraguay-n599977.html.

814 Gras, C., and V. Hernández. 2016. *Radiografía del nuevo campo argentino: del terrateniente*
815 *al empresario transnacional*. Buenos Aires: Siglo XXI Editores.

816 Grau, H. R., N. I. Gasparri, and T. M. Aide. 2005. Agriculture expansion and deforestation in
817 seasonally dry forests of north-west Argentina. *Environmental Conservation* 32 (2):140.

Grugel, J., and P. Riggirozzi. 2012. Post-neoliberalism in Latin America: Rebuilding and Reclaiming the State after Crisis. *Development and Change* 43 (1):1–21.

Hecht, S. B. 1985. Environment, development and politics: Capital accumulation and the livestock sector in Eastern Amazonia. *World Development* 13 (6):663–684.

———. 2005. Soybeans, Development and Conservation on the Amazon Frontier. *Development and Change* 36 (2):375–404.

Hoyos, L. E. et al. 2013. Deforestation and precipitation patterns in the arid Chaco forests of central Argentina ed. G. Henebry. *Applied Vegetation Science* 16 (2):260–271.

Jepson, W., C. Brannstrom, and A. Filippi. 2010. Access Regimes and Regional Land Change in the Brazilian Cerrado, 1972–2002. *Annals of the Association of American Geographers* 100 (1):87–111.

Jepson, W. E. 2006. Producing a modern agricultural frontier: Firms and cooperatives in eastern Mato Grosso, Brazil. *Economic Geography* 82 (3):289–316.

Jepson, W. E., C. Brannstrom, and A. Filippi. 2010. Access Regimes and Regional Land Change in the Brazilian Cerrado, 1972-2002. *Annals of the Association of American Geographers* 100 (1):87–111.

Kaimowitz, D., and J. Smith. 2001. Soybean technology and the loss of natural vegetation in Brazil and Bolivia. In *Agricultural Technologies and Tropical Deforestation*, eds. A. Angelsen and D. Kaimowitz, 195–212. Wallingford, Oxon, UK: CABI International.

Kaimowitz, D., G. Thiele, and P. Pacheco. 1999. The Effects of Structural Adjustment on Deforestation and Forest Degradation in Lowland Bolivia. *World Development* 27 (3).

Killeen, T. J. et al. 2008. Total Historical Land-Use Change in Eastern Bolivia: Who, Where, When, and How Much ? *Ecology And Society* 13 (1):36.

Klintowitz, J. 1995. O País pula a cerca. *Veja* :60–67.

De Koninck, R. 2000. The theory and practice of frontier development: Vietnam's contribution. *Asia Pacific Viewpoint* 41 (1):7–21.

de L.T. Oliveira, G. 2013. Land Regularization in Brazil and the Global Land Grab. *Development and Change* 44 (2):261–283.

Levins, R. A., and W. W. Cochrane. 2010. The Treadmill Revisited. *Land Economics* 72 (4):550–553.

Lorenzatti, S. 2007. Un Cordobés en Bolivia. *Clarín*. http://edant.clarin.com/suplementos/rural/2007/12/15/r-01564515.htm.

McKay, B., and G. Colque. 2015. Bolivia's soy complex: the development of "productive exclusion." *The Journal of Peasant Studies* 43 (2):583–610.

Miller, E. S. 2001. *Peoples of the Gran Chaco*. Greenwood Publishing Group.

Morello, J. H. 2005. Etapas de uso de los recursos y desmantelamiento de la biota del chaco. In *Situación ambiental Argentina 2005*, eds. A. D. Brown et al., 83–90.

Morello, J. H., W. Pengue, and A. F. Rodriguez. 2005. Un siglo de cambios de diseño del paisaje: el Chaco Argentino. In *Primeras Jornadas Argentinas de Ecología del paisaje*, 1–31.

Morini, G. 2011. Una fortuna hecha de favores fiscales. *Página/12* 14 February. https://www.pagina12.com.ar/diario/elpais/1-162319-2011-02-14.html (last accessed 7 June 2017).

Müller, R., D. M. Larrea-Alcázar, S. Cuéllar, and S. Espinoza. 2014. Causas directas de la deforestación reciente (2000-2010) y modelado de dos escenarios futuros en las tierras bajas de Bolivia. *Ecología en Bolivia* 49 (1):20–34.

Müller, R., D. Müller, F. Schierhorn, G. Gerold, et al. 2011. Proximate causes of deforestation in the Bolivian lowlands: an analysis of spatial dynamics. *Regional Environmental Change* 12 (3):445–459.

Müller, R., P. Pacheco, and J. Montero. 2014. *The context of deforestation and forest degradation in Bolivia: Drivers, agents and institutions*. Bogor, Indonesia.

Muñoz, L. 2015. Grobocopatel: "Chaco está lleno de oportunidades y desafíos que requieren inversión" | Diario Norte Chaco. *Diario Norte*.

Nolte, C., Y. le Polain de Waroux, J. Munger, T. N. P. Reis, et al. 2017. Conditions influencing the adoption of effective anti-deforestation policies in South America's commodity frontiers. *Global Environmental Change* (43):1–14.

Olson, D. M. et al. 2001. Terrestrial Ecoregions of the World: A New Map of Life on Earth. *BioScience* 51 (11):933.

Pacheco, P. 2012. Actor and frontier types in the Brazilian Amazon: Assessing interactions and outcomes associated with frontier expansion. *Geoforum* 43 (4):864–874.

———. 2009. Agrarian change, cattle ranching and deforestation: Assessing their linkages in southern Pará. *Environment and History* 15 (4):493–520.

———. 2006. Agricultural expansion and deforestation in lowland Bolivia: the import substitution versus the structural adjustment model. *Land Use Policy* 23 (3):205–225.

———. 2005. Populist and capitalist frontiers in the Amazon: diverging dynamics of agrarian and land-use change.

Paolasso, P., J. Krapovickas, and N. Gasparri. 2012. Deforestación, expansión agropecuaria y dinámica demográfica en el Chaco Seco Argentino durante la década de los noventa. *Latin American Research Review* 47 (1).

Pérez Luna, M. 2007. *No todo grano que brilla es oro: un análisis de la soya en Bolivia* ed. CEDLA. La Paz, Bolivia.

Piñeiro, D. 2012. Land grabbing : concentration and "foreignisation" of land in Uruguay. *Canadian Journal of Development Studies/Revue canadienne d'études du développement* 33 (4):471–489.

le Polain de Waroux, Y., R. D. Garrett, R. Heilmayr, and E. F. Lambin. 2016. Land-use policies and corporate investments in agriculture in the Gran Chaco and Chiquitano. *Proceedings of the National Academy of Sciences* 113 (15):4021–4026.

Qaim, M., and G. Traxler. 2005. Roundup Ready soybeans in Argentina : farm level and aggregate welfare effects. *Agricultural Economics* 32:73–86.

Redo, D., A. C. Millington, and D. Hindery. 2011. Deforestation dynamics and policy changes in Bolivia's post-neoliberal era. *Land Use Policy* 28 (1):227–241.

Reuters. 2005. Paraguay, sin aftosa. *La Nación* 20 January. http://www.lanacion.com.ar/672552-paraguay-sin-aftosa.

Richards, P. 2015. What Drives Indirect Land Use Change? How Brazil's Agriculture Sector Influences Frontier Deforestation. *Annals of the Association of American Geographers* 105 (5):1026–1040.

Richards, P. D. 2012. Food, fuel, and the hidden margins of capital. *Journal of Land Use Science* 7 (3):289–310.

Rindfuss, R. R. et al. 2007. Frontier Land Use Change: Synthesis, Challenges, and Next Steps. *Annals of the Association of American Geographers* 97 (4):739–754.

Rodrigues, A. S. L. et al. 2009. Boom-and-bust development patterns across the Amazon deforestation frontier. *Science* 324 (5933):1435–7.

Rudel, T. K. 2007. Changing agents of deforestation: From state-initiated to enterprise driven processes, 1970-2000. *Land Use Policy* 24 (1):35–41.

Sacchi, L. V., and N. I. Gasparri. 2015. Impacts of the deforestation driven by agribusiness on urban population and economic activity in the Dry Chaco of Argentina. *Journal of Land Use Science* 4248 (October):1–17.

Schierhorn, F. et al. 2016. The dynamics of beef trade between Brazil and Russia and their environmental implications. *Global Food Security* :1–9.

di Tella, G. 1982. The Economics of the Frontier. In *Economics in the Long View*, eds. C. Kindleberger and G. di Tella, 210–27. Palgrave Macmillan UK.

Torres, R., N. I. Gasparri, P. G. Blendinger, and H. R. Grau. 2014. Land-use and land-cover effects on regional biodiversity distribution in a subtropical dry forest: a hierarchical integrative multi-taxa study. *Regional Environmental Change* 14 (4):1549–1561.

Urioste, M. 2012. Concentration and "foreignisation" of land in Bolivia. *Canadian Journal of Development Studies/Revue canadienne d'études du développement* 33 (4):439–457.

Vázquez, F. 2013. *Geografía humana del Chaco paraguayo* ADEPO. Asunción.

Velázquez, M. R. 2012. El 60% de frigoríficos exportadores son controlados por firmas brasileñas. *ABC Color* 27 November. http://www.abc.com.py/edicion-impresa/economia/el-60-de-frigorificos-exportadores-son-controlados-por-firmas-brasilenas-482655.html.

Viglizzo, E. F. et al. 2011. Ecological and environmental footprint of 50 years of agricultural expansion in Argentina. *Global Change Biology* 17 (2):959–973.

Vivaldi, A. 2011. Stuck on a Muddy Road: Frictions of Mobility amongst Urban Toba in Northern Argentina. *Identities: Global Studies in Culture and Power* 18 (6):599–619.

Walker, R. et al. 2009. Ranching and the new global range: Amazônia in the 21st century. *Geoforum* 40 (5):732–745.

———. 2004. Theorizing Land-Cover and Land-Use Change: The Case of Tropical Deforestation. *International Regional Science Review* 27 (3):247–270.

Zak, M. R., M. Cabido, D. Cáceres, and S. Díaz. 2008. What drives accelerated land cover change in central Argentina? Synergistic consequences of climatic, socioeconomic, and technological factors. *Environmental management* 42 (2):181–9.

Zak, M. R., M. Cabido, and J. G. Hodgson. 2004. Do subtropical seasonal forests in the Gran Chaco, Argentina, have a future? *Biological Conservation* 120 (4):589–598.

Zoomers, A. 2003. Land liberalisation and sustainable development in Latin America: Unravelling the land sales market of Santa Cruz, Bolivia. *International Development Planning Review* 25 (3):245–262.

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Figure Captions

Figure 1: Study area and main places mentioned in the paper. Administrative units (provinces, departments, states): BA = Buenos Aires; CA = Catamarca; CO = Córdoba; CH = Chaco; JU = Jujuy; FO = Formosa; MS = Mato Grosso do Sul; PR = Paraná ; SA = Salta; SC = Santa Cruz; SE = Santiago del Estero; SF = Santa Fe; SP = São Paulo; TU = Tucumán. "S.C. de la Sierra" is Santa Cruz de la Sierra, and "S.M. de Tucumán" is San Miguel de Tucumán. The Humid Pampas are indicated as one region from which multiple actors in the Chaco frontiers originate.

Figure 2: Rents and dynamics of frontier expansion. A & C: Pre- and post-frontier equilibrium where bid rent equals economic rent, and the transition to uncultivated land (f) happens where rent is zero (assuming zero rent for uncultivated land). B: Frontier situation where the economic rent exceeds the bid rent, generating an "abnormal" rent and a frontier space F where expansion may happen. D: Rent curves under a scenario of technological innovation

for a typical actor (X) and an actor with the ability to build access roads (Y). Innovation increases the economic rent for all, shifting the bid rent curve up and bringing the frontier from f to f′, but Y's ability to improve access at the margin changes the angle of her rent curve, shifting the frontier to f″ and creating a space of "differential rents" dF, where land investments (i) are profitable only to her. E: Stages of frontier succession. After an abnormal rent is created, investments flow to the region, leading to an increase in agricultural area and bid rent. As the bid rent catches up with the economic rent, the abnormal rent disappears, causing a slowdown in agricultural expansion. Note that while a steep increase in economic rent is represented here for simplicity, the curve can take more complex forms, such as a stepwise increase.

Figure 3: Rents, Actors and frontiers. The development of commodity frontiers is a function of factors creating rents, and of the characteristics of actors that enable them to capture these rents.

Figure 4: Frontiers of the Gran Chaco. A: Forest cover and deforestation rates for 10-km radius hexagons; B: Dominant land use at the end of the period; C: Active frontiers, i.e., areas with high to medium deforestation rates and forest cover, differentiated based on the geographic origin of their expansion. Data from (Baumann et al. 2016)).

Figure 5: Evolution of land uses (in percent, left axis) and average land prices (in thousand US dollars, right axis) in each active frontier. Land use proportions are from (Baumann et al. 2016), and land prices from (le Polain de Waroux, Garrett, Heilmayr, and Lambin 2016). We delineated frontiers manually on the map of frontier areas (Figure 4C), based on contiguity and direction of expansion.

1042 **Figures**

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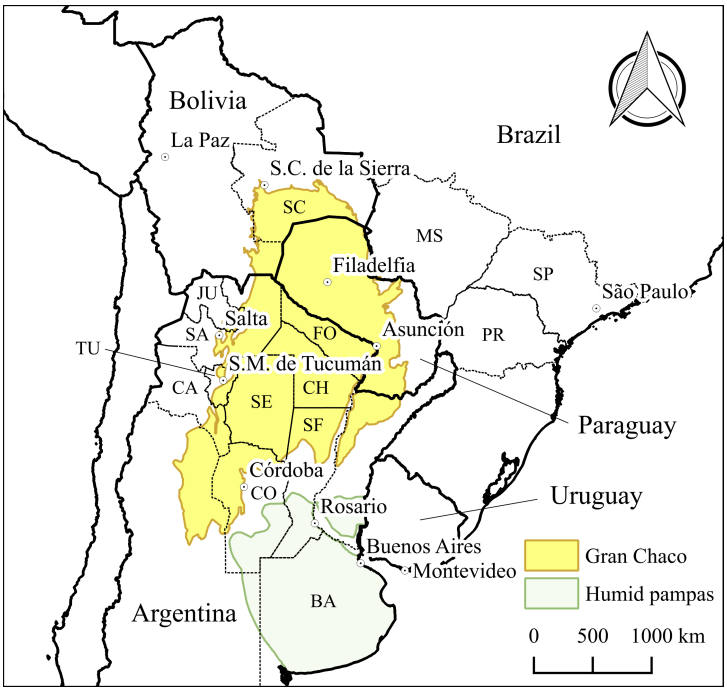
1044 **Figure 1**



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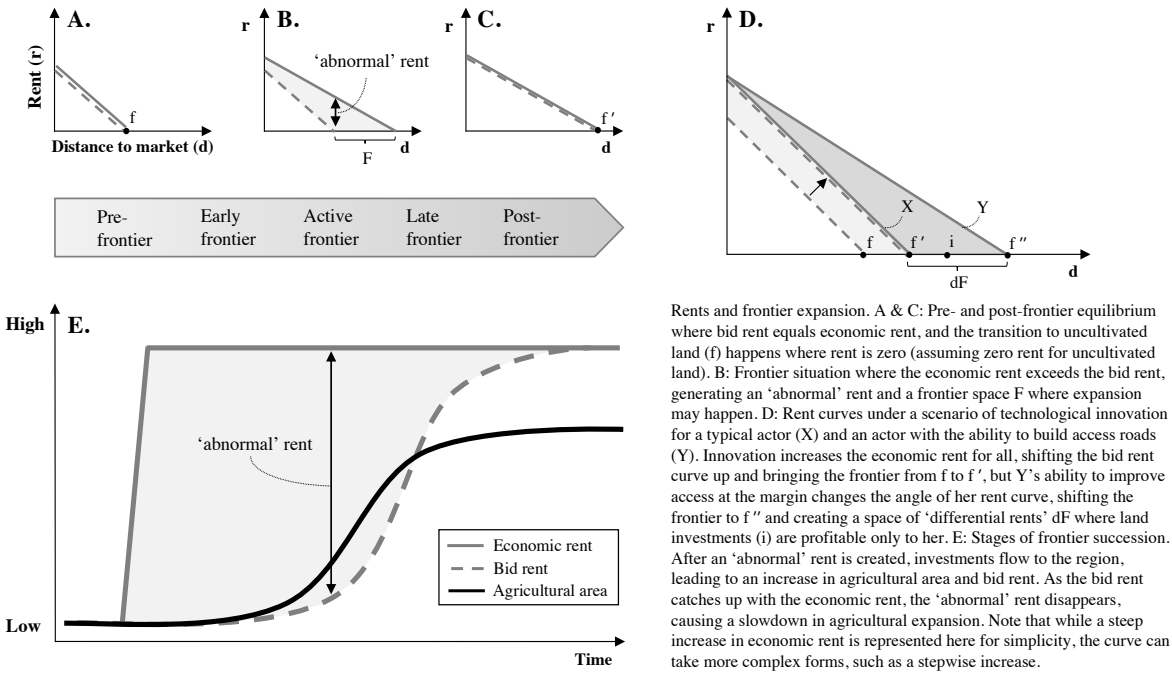
1046 **Figure 2**



Rents and frontier expansion. A & C: Pre- and post-frontier equilibrium where bid rent equals economic rent, and the transition to uncultivated land (f) happens where rent is zero (assuming zero rent for uncultivated land). B: Frontier situation where the economic rent exceeds the bid rent, generating an 'abnormal' rent and a frontier space F where expansion may happen. D: Rent curves under a scenario of technological innovation for a typical actor (X) and an actor with the ability to build access roads (Y). Innovation increases the economic rent for all, shifting the bid rent curve up and bringing the frontier from f to f ′, but Y's ability to improve access at the margin changes the angle of her rent curve, shifting the frontier to f ″ and creating a space of 'differential rents' dF where land investments (i) are profitable only to her. E: Stages of frontier succession. After an 'abnormal' rent is created, investments flow to the region, leading to an increase in agricultural area and bid rent. As the bid rent catches up with the economic rent, the 'abnormal' rent disappears, causing a slowdown in agricultural expansion. Note that while a steep increase in economic rent is represented here for simplicity, the curve can take more complex forms, such as a stepwise increase.

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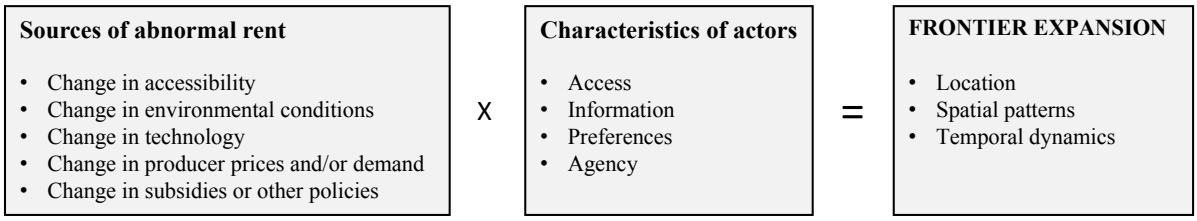
1049 **Figure 3**



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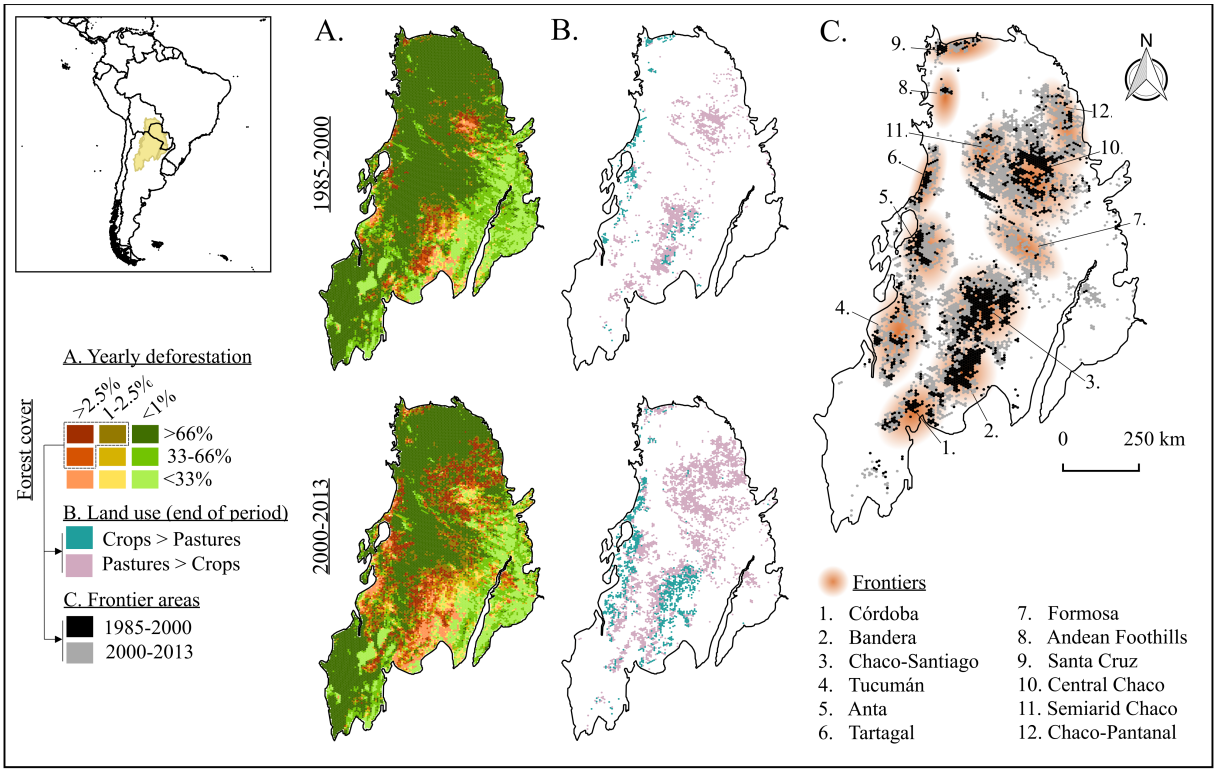
1051 **Figure 4**



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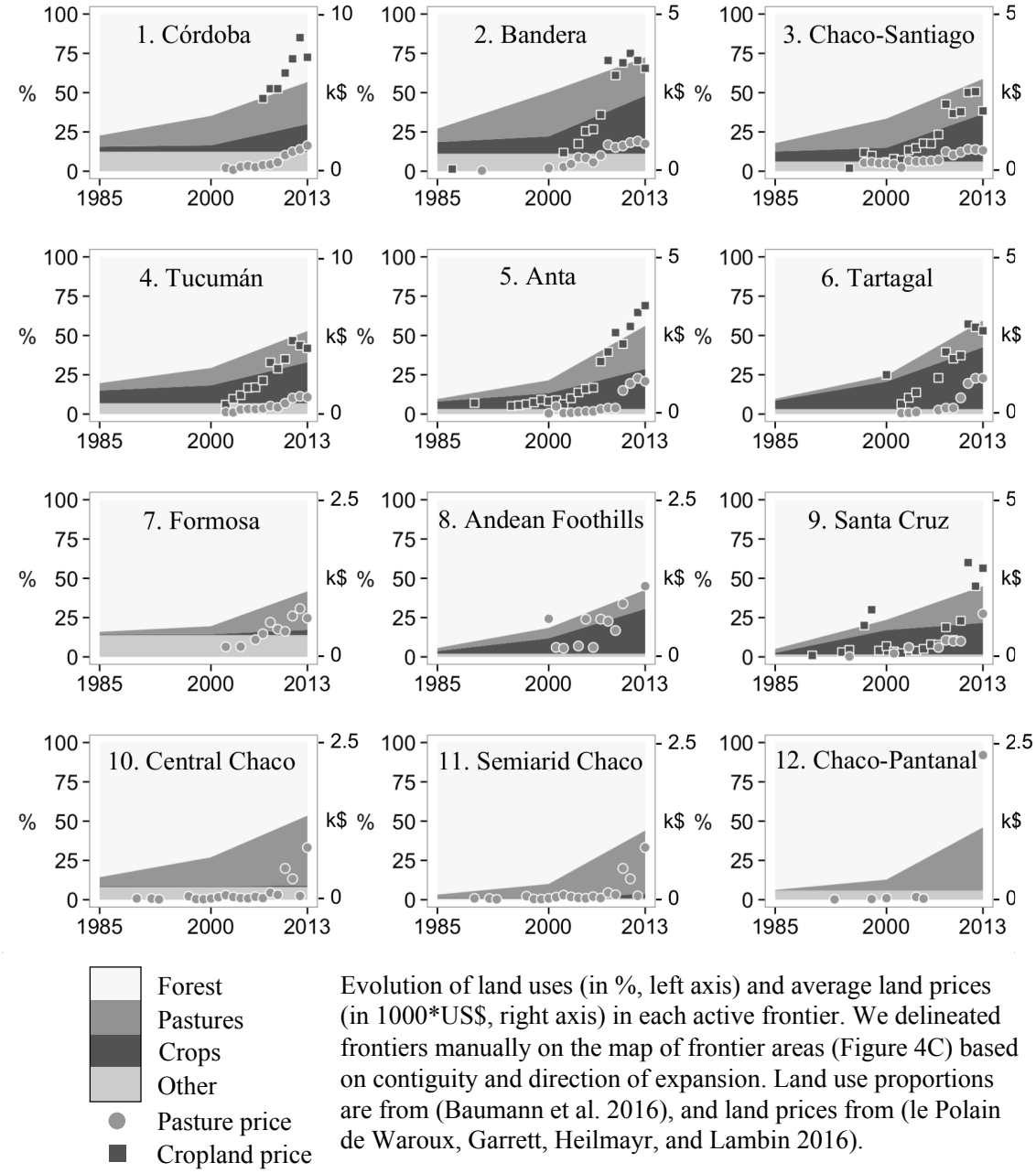
1054 **Figure 5**



Evolution of land uses (in %, left axis) and average land prices (in 1000*US$, right axis) in each active frontier. We delineated frontiers manually on the map of frontier areas (Figure 4C) based on contiguity and direction of expansion. Land use proportions are from (Baumann et al. 2016), and land prices from (le Polain de Waroux, Garrett, Heilmayr, and Lambin 2016).

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Tables

Table 1

	Argentina		Bolivia		Paraguay	
	#	*Affiliations of interviewees*	*#*	*Affiliations of interviewees*	*#*	*Affiliations of interviewees*
Agricultural producers*	**46**	n.a.	**37**	n.a.	**43**	n.a.
Agricultural cooperatives and lobbies	**9**	Asociación Argentina de Grupos CREA (AACREA), Asociación Argentina de Productores en Siembra Directa (AAPRESID), Grupo Lajitas, PROGRANO, Sociedad Rural Argentina (SRA)	**10**	Asociación Boliviana de grupos CREA (ABCREA), Asociación de Productores de Oleaginosas y trigo (ANAPO), Federación de Ganaderos de Santa Cruz (FEGASACRUZ), UNISOYA, Cámara de Exportadores (CADEX), Instituto Boliviano de Comercio Exterior (IBCE)	**10**	Asociación de Grupos CREA de Paraguay, Cooperativa Chortitzer, Cooperativa Fernheim, Cooperativa Neuland
Industry and services*	**8**	Bunge, Cargill	**3**	ADM-SAO, Asociación de Proveedores de Insumos Agropecuarios (APIA)	**6**	n.a.
Research and extension services	**16**	Instituto Nacional de Tecnología Agropecuaria (INTA), Universidad Nacional de Córdoba, Universidad Nacional del Noreste, Universidad Nacional de Salta	**4**	Centro de Investigación Agrícola Tropical (CIAT), Universidad Autonoma Gabriel René Moreno	**2**	Universidad Nacional de Asunción
Social and environmental NGOs	**3**	Fundapaz, Movimiento Campesino de Santiago del Estero (MOCASE), Proyungas, Red Agroforestal Chaco Argentina (REDAF)	**14**	Centro de Estudios Jurídicos e Investigación Social (CEJIS), Centro de Investigación y Promoción del Campesinado (CIPCA), Fundación Amigos de la Naturaleza (FAN), Fundación Natura, Fundación para la Conservación del Bosque Chiquitano, Fundación Tierra, Museo de Historia Natural Noel Kempff Mercado, PROBIOMA, Sociedad Boliviana de Derecho Ambiental (SBDA), World Wildlife Fund (WWF)	**12**	Asociación de Servicios de Cooperación Indígena - Mennonita, (ACSIM), BASE Investigaciones Sociales, Fundación Moises Bertoni, Fundación DesdelChaco, Guyra Paraguay, Instituto de Derecho y Economia Ambiental (IDEA), Red Paraguaya de Conservación en Tierras Privadas, Wildlife Conservation Society (WCS) World Wildlife Fund (WWF)
Government organizations	**3**	Dirección de Bosques de la provincia del Chaco, Dirección de Bosques de la provincia de Santiago del Estero	**3**	Autoridad de Fiscalización y Control de Bosques y Tierras (ABT); Servicio Nacional de Areas Protegidas (SERNAP)	**7**	Instituto Forestal Nacional (INFONA), Municipalidad de Filadelfia, Gobernación de Boquerón, Secretaria del Ambiente (SEAM), Servicio Nacional de Calidad y Salud Animal (SENACSA)

**) Agricultural producers and small-scale services companies are not named for privacy reasons; producers who also have industry and/or services activities are counted only once as producers*

Table 2

			ARGENTINA						
	Description	**Period**	**1. Cordoba**	**2. Bandera**	**3. Chaco-Santiago**	**4. Tucumán**	**5. Anta**	**6. Tartagal**	**7. Formosa**
Size of the active frontier	*The total area (in Mha) of active frontier (area of land described as "active frontier" in Figure 4C.)*	1985-2000	0.8	1.3	2.4	0.7	0.5	0.3	0.1
		2000-2013	1.4	1.2	4.1	2.3	1.6	0.7	1.6
Deforestation rate	*Area deforested as a percentage of total forest area in the "active frontier" at the beginning of the period*	1985-2000	16%	32%	15%	12%	13%	16%	4%
		2000-2013	33%	45%	36%	33%	44%	46%	28%
Drivers of expansion	*Changes in pasture (P.) and cropland (C.) area as a % of total deforested area in active frontier*	1985-2000	93% P. — 7% C.	84% P. — 16% C.	85% P. — 15% C.	66% P. — 34% C.	56% P. — 44% C.	19% P. — 81% C.	99% P. — 1% C.
		2000-2013	37% P. — 63% C.	-17% P. — 117% C.	15% P. — 85% C.	37% P. — 63% C.	55% P. — 45% C.	38% P. — 62% C.	88% P. — 12% C.
Main actors	*Principal actors involved directly in the conversion of land to agriculture*	1985-2013	Capitalized farmers from the core agricultural areas of Córdoba	Small-scale (1990s) and capitalized medium-scale farmers (2000s) from Santa Fe and Córdoba	Capitalized medium-scale farmers from Buenos Aires, Santa Fe and Córdoba	Capitalized farmers from Tucumán linked to sugar cane production	Capitalized large-scale farmers from Salta, Jujuy, Santa Fe and Buenos Aires; some US and EU companies	Capitalized farmers from Salta, Jujuy and Buenos Aires; some US and EU companies	Capitalized farmers from Córdoba, Buenos Aires and Chaco
Sources of increasing rent	Technological innovation	1985-2013	No-till agriculture and genetically modified (GM) roundup-resistant (RR) soy in 1996; storage bags mid-1990's; introduction of new pasture varieties						
	Change in environmental conditions	1985-2013	Gradual increase in rainfall in northeast part of frontier	Gradual increase in rainfall (over the second half of the 20th century)					
	Change in accessibility	1985-2013	Major changes predate the study period			Road 34 pavement completed in 2005	Roads 5, 16 and 30 paved in the 2000s	Dirt road network left by petroleum exploration; road 81 pavement completed in 2009	Road 81 pavement completed in 2009
	Change in producer prices and/or demand	1985-2013	Currency devaluation in 2001; booming world price for soy in late 1990s and mid-2000s						
	Subsidies and other public policies	1985-2013	Repayment in pesos of debts contracted in dollars after 2001 devaluation.						

			BOLIVIA		PARAGUAY		
	Description	**Period**	**8. Santa Cruz**	**9. Andean Foothills**	**10. Central Chaco**	**11. Semiarid Chaco**	**12. Chaco-Pantanal**
Size of the active frontier	*The total area (in Mha) of active frontier (area of land described as "active frontier" in Figure 4C.)*	1985-2000	0.3	0.1	2.2	0.4	0.4
		2000-2013	0.5	0.3	4.5	1.7	2.0
Deforestation rate	*Area deforested as a percentage of total forest area in the "active frontier" at the beginning of the period*	1985-2000	19%	14%	15%	7%	7%
		2000-2013	28%	30%	36%	38%	38%
Drivers of expansion	*Changes in pasture (P.) and cropland (C.) area as a % of total deforested area in active frontier*	1985-2000	22% P. — 78% C.	36% P. — 64% C.	100% P. — 0% C.	99% P. — 1% C.	100% P. — 0% C.
		2000-2013	79% P. — 21% C.	23% P. — 77% C.	99% P. — 1% C.	93% P. — 7% C.	100% P. — 0% C.
Main actors	*Principal actors involved directly in the conversion of land to agriculture*	1985-2013	Mennonite colonies; farmers from Santa Cruz; Brazilians farmers from Paraná and Mato Grosso do Sul (1990s); Argentine farmers from Córdoba, BsAs and Salta (2000s)	Farmers from Santa Cruz; Mennonite colonies	Mennonite farmers; foreign investors (Uruguay, Brazil, Chile and others) with Mennonite administrators	Mennonite farmers; capitalized East Paraguayan and Brazilian farmers; Uruguayan and other foreign investors (Argentina, Brazil and others) with Mennonite administrators	Capitalized Brazilian farmers from Mato Grosso do Sul and São Paulo states; Mennonite and East Paraguayan farmers and investors (2000s); Uruguayan investors with Mennonite administrators, and some Argentine companies (late 2000s)
Sources of increasing rent	Technological innovation	1985-2013	No-till agriculture (>1996) and GM RR soy (legalized in 2005, but introduced illegally before); new pasture varieties (e.g., *Panicum maximum*, late 1980s)		New pasture varieties (e.g., *Panicum maximum* in the mid-1980s, *Tanzania* & *Bracchiaria* in the 2000s); genetic improvements in cattle; new deforestation techniques ; new water harvesting and storage techniques		
	Change in environmental conditions	1985-2013	No change in rainfall has been documented				
	Change in accessibility	1985-2013	Improvement of road network by government (1986-91) and under Eastern Lowlands project (1989-1996); Road 4 to Brazil paved late 2000s	Road Santa Cruz-Tarija (paved early 2000s); grid of dirt roads left by previous petroleum exploration	Trans-chaco highway pavement completed in 2008; New all-weather roads throughout the Chaco, built by Mennonites and other investors		
	Change in producer prices and/or demand	1985-2013	Currency devaluation & removal of price controls in 1985; Increase in demand for soy following opening of CAN free trade zone in 1992; booming world prices for soy after 2006		Sharp increase in prices due to increased exports following improvement in sanitary conditions (eradication of foot-and-mouth disease in 2005).		
	Subsidies and other public policies	1985-2013	[Currency devaluation in 1985]; suppression of export taxes and reduced tariffs after 1985; cheap loans for agriculture in the 1980's		None		