



Research, part of a Special Feature on [Land Acquisitions, Well-being, and Environment](#)

Two of a kind? Large-scale land acquisitions and commodity frontier expansion in Argentina's Dry Chaco

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ABSTRACT. Land-use change (LUC) driven by commodity agriculture over the last 20 years has been particularly extensive in the Dry Chaco region of Argentina, which surpassed the Amazon during that time to become one of the top three global deforestation hotspots. Large-scale land acquisitions (LSLAs) have been cited as a key catalyst of deforestation and related LUC in commodity frontier expansion. However, it is unclear whether contemporary LSLAs that affected the Dry Chaco and other agricultural commodity frontiers globally differed in their mechanisms of LUC from conventional agricultural expansion processes. The diversity of domestic and foreign investors, commodity crops, and LUC dynamics observable in contemporary LSLAs in Argentina's Dry Chaco provide a focused lens, or "case set," through which to consider commodity frontier dynamics in the Salta Province since 2000. We integrated remote sensing analysis and classification of the timing and location of LUC within the boundaries of LSLA and non-LSLA agricultural parcels with survival analysis to draw conclusions about the dynamics of LSLA establishment (i.e., purchase/transfer of ownership/title change) and LUC associated with production operations. Regionally, spatio-temporal patterns of agricultural expansion into increasingly marginal land were consistent between LSLA and non-LSLA parcels. However, parcel-based analysis revealed differing responsiveness to commodity prices and land-use constraints imposed by the National Forest Law, which translated into diverging LUC trajectories among LSLA and non-LSLA parcels. In particular, LUC on LSLA parcels was significantly slowed by Forest Law constraints, but continued on non-LSLA parcels and a small number of "recategorized" and/or illegally deforested LSLA parcels. Our findings demonstrate the importance of moving beyond large-scale, aggregate spatial assessments of LSLA outcomes that aim to inform policy yet "black box" actors. Actor heterogeneity must be explicitly accounted for as part of the causal mechanisms that influence land acquisition and lead to differing LUC trajectories.

Key Words: *deforestation; foreign direct investment; land grabs; poorly selective contagion*

INTRODUCTION

Large-scale land acquisitions (LSLAs) have emerged as a major catalyst for agricultural frontier expansion and associated deforestation globally (Anseeuw et al. 2013a, Messerli et al. 2014, Davis et al. 2020). Although LSLAs, broadly defined, are not a new phenomenon (White 2012, Edelman 2013), contemporary (post-2000) LSLAs have arisen within the context of unprecedented global economic connectivity, unique triggering events (i.e., food, fuel, and financial crises; Zoomers 2010), and new commodity production (e.g., flex crops; Borrás et al. 2016) or investment intents (Fairbairn 2014). Contemporary LSLAs are associated with a "new wave" of commodity frontier expansion driven by transnational flows of capital and commodities, which represents an evolution of historical agricultural frontiers. Newer conceptualizations of commodity frontiers emphasize interactions between local actors and state-level policies, as well as the differential abilities of actors to access rents, and attempts to account for the importance of agro-ecological, socio-political, and economic interactions across local, national, regional, and global scales (e.g., le Polain de Waroux et al. 2018). The diversity of domestic and foreign investors, commodity crops, and land-use change (LUC) dynamics observable in contemporary LSLAs—here defined as land transactions that entail a transfer of rights to use, control, or own land through sale, lease, or concession, greater than 200 ha, and concluded since the year 2000 (Anseeuw

et al. 2013a)—provide a focused lens, or "case set," through which to consider commodity frontier dynamics.

Large-scale land acquisitions have received considerable international research attention (e.g., Anseeuw et al. 2013b, Liao et al. 2016, Oberlack et al. 2016, D'Odorico et al. 2017, International Land Coalition (ILC) et al. 2018) with ongoing and targeted monitoring efforts, and thus offer discrete, remotely observable (i.e., satellite imagery), and spatially bounded units of analysis to investigate the localized frontier LUC dynamics linked to regional and global markets. However, there has been limited interaction between LSLA and commodity frontier literatures, primarily because LSLA research efforts have tended to focus on either LUC or social conflict and land dispossession associated with LSLA, rather than how those outcomes causally relate. Current knowledge of the causes and consequences of contemporary LSLA is largely in the form of descriptive analyses at the global- or regional-scale assessments (e.g., sub-Saharan Africa or Southeast Asia; Borrás and Franco 2011, Borrás et al. 2012, Messerli et al. 2014, Oberlack et al. 2016, Dell'Angelo et al. 2017, Davis et al. 2020) or in-depth political ecology or ethnographic analyses of one or a small number of cases (e.g., Dwyer 2014, Baird and Fox 2015, Lamb et al. 2017, Fox et al. 2018). Coincident information about LSLA actors, land transaction processes, and spatially explicit boundary data is

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limited (Anseeuw et al. 2013b, Liao et al. 2016), which hampers quantification and inference about the specific causes of attributable LUC (Messerli et al. 2014, Magliocca et al. 2019).

Large-scale land acquisitions in the Argentinian Dry Chaco are an exception. This is due in part to the rapid and extensive expansion of the agricultural commodity frontier in this region. Over the last 20 years, the Dry Chaco region of Argentina surpassed the Amazon to become one of the top three global deforestation hotspots owing to extensive agricultural expansion (Hansen et al. 2013, Volante et al. 2016, Baumann et al. 2017). The northern province of Salta has been particularly targeted by large-scale agriculture investors, with about 1.5 million hectares in LSLAs (as of 2018) (Venencia et al. 2019). Domestic investors accounted for 92% of the LSLAs, and the remaining 8% were international investors from France, Luxemburg, Spain, the Netherlands, the USA, and Uruguay, among others (Salas Barboza et al. 2019). Land-use change in the two most affected departments of Salta province (Anta and San Martín) from 2000–2013 was rapid and extensive, with deforestation rates of 44% and 46%, respectively (le Polain de Waroux et al. 2018). Consequently, LSLAs in Salta are the best documented in the Argentinian Dry Chaco, and among the best documented globally due to ongoing monitoring by the Land Matrix Initiative Latin America Focal Point (Venencia et al. 2019). As such, they provide a unique opportunity to study two globally significant phenomena—commodity frontier expansion and LSLAs—on a case-by-case basis, and which inherently link global commodity markets, national political and economic conditions, and local LUC dynamics.

Commodity Frontier Expansion in the Dry Chaco

Land-use change in the Dry Chaco has been and continues to be a complex, multi-scale process driven by fundamental shifts in economic and geopolitical relations linking sovereign states, global finance, and agribusiness to local groups (Cotula 2012). Locally, the introduction of key agricultural technologies, specifically Roundup Ready soybean cultivars and storage bags, contributed to the soy boom in the 1990s (Volante et al. 2016, le Polain de Waroux et al. 2018). Genetically modified soy cultivars prompted the transition to no-till cultivation practices, and storage bags enabled expansion of soy production into areas without storage infrastructure (Goldfarb and van der Haar 2016). At the national level, several economic crises, currency devaluations, and export tariffs (Dowd 2009, Volante et al. 2016, Meador and Sandoval 2018, le Polain de Waroux et al. 2018) variously promoted or constrained agricultural expansion. Across the Dry Chaco region, the soy boom coincided with a period of increased mean annual precipitation (Grau et al. 2005, Volante et al. 2016). Globally, increasing agricultural demand and commodity trade (Tilman et al. 2011, Kastner et al. 2014, MacDonald et al. 2015), particularly for soybeans and soy products, supported the growth of Argentina's exports (Simoes and Hidalgo 2011). With increasing agricultural demand from global commodity markets, outside investors—from neighboring provinces, such as from the Pampas region, or multinational corporations—transformed the Dry Chaco from an agricultural to commodity frontier (Goldfarb and van der Haar 2016, le Polain de Waroux et al. 2018). Across South America, the geographical and sectoral coupling of the soybean and cattle sectors further generated new channels for capital to promote deforestation

owing to leakage, and increasingly challenged more common regulatory schemes (Gasparri and le Polain 2015, Fehlenberg et al. 2017).

Despite high rates of deforestation, the Dry Chaco of Argentina still contains nearly 8.4 million hectares of forest—2.4 million hectares of which is contained in Salta province, which has the highest rate of agricultural expansion within the Argentinian Chaco (le Polain de Waroux et al. 2018). The remaining forest supports a wealth of biodiversity (Piquer-Rodríguez et al. 2015), carbon sequestration (Gasparri et al. 2008), and traditional indigenous and smallholder livelihoods (Seghezzo et al. 2011). Forest loss was and continues to be caused by rapid and extensive expansion of cattle ranching and export-oriented agriculture (Piquer-Rodríguez et al. 2018). Concern over the rate of forest loss prompted the passing of the “Native Forest Law” to protect the remaining forest (Seghezzo et al. 2011). Although the law seems to have reduced forest loss in some areas, it remains contested and overall deforestation continues to be high, including some illegal deforestation, due to low enforcement (Nolte et al. 2017, 2018, Volante and Seghezzo 2018, Vallejos et al. 2021). Commodity frontier expansion pressures, of which LSLAs are a primary source, continue to challenge conservation in Argentina's Dry Chaco.

Here, we use the conceptual frameworks of commodity crop expansion pathways, applied to commodity crop expansion in Salta including the “case set” of LSLA in Salta province, to examine how LSLA may conform with or diverge from the typical LUC dynamics associated with commodity frontiers. Specifically, we address the following research questions:

- How do agricultural commodity markets, provincial land-use governance, local agro-ecological conditions, and types of commodity agriculture actors influence the timing and rate of direct LUC among agricultural parcels?
- How do the LUC trajectories of LSLAs differ from those observed in other (i.e., non-LSLA) agricultural parcels?

We integrate remote sensing analysis and classification of the timing and location of LUC within the boundaries of LSLA and non-LSLA agricultural parcels with survival analysis to draw conclusions about the dynamics of LSLA establishment (i.e., purchase/transfer of ownership/title change) and implementation (i.e., LUC associated with production operations). The next section details our application and interpretation of the theoretical frameworks of commodity frontier expansion (le Polain de Waroux et al. 2018) and commodity crop expansion pathways (Meyfroidt et al. 2014) through the lens of LSLA. The subsequent sections present methods for LUC analysis and spatially and temporally explicit results. We conclude with a discussion of LSLA dynamics in Salta, conformance and divergence of LUC dynamics between LSLA and non-LSLA parcels, the effectiveness of Salta's implementation of the Forest Law, and the applicability of the commodity frontier expansion model for understanding LSLA in Salta province and globally.

Theoretical Framework

Two theoretical frameworks shape our investigation into the timing and extent of commodity crop expansion in Salta province in Argentina. le Polain de Waroux et al. (2018) propose a neoclassical and political economy framework for understanding

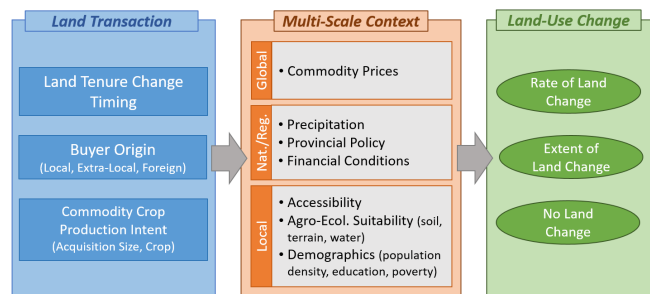
the conditions under which agricultural frontiers expand through commodity crop production. Applied to the South American Gran Chaco, the framework emphasizes the interaction between two main processes: the creation of “abnormal rents” and the differential ability of actors to capture those rents. “Abnormal rents” are economic rents generated above land prices in frontier regions due to changes in accessibility (e.g., roads, supply chain facilities), land productivity (e.g., agro-ecological conditions), agricultural technology, producer prices or demands for specific agricultural commodities, and local to national policies that reduce production cost (e.g., subsidies). Importantly, changes in these factors can arise at multiple scales, either from within or external to production regions, to create abnormal rents. However, as le Polain de Waroux and colleagues (2018) emphasize, these conditions alone are not sufficient to catalyze frontier expansion, which additionally depends on the ability of actors to capture increased economic rents. In particular, commodity frontier expansion occurs when actors have access to rent information, can readily mobilize capital to secure factors of production, have suitable risk and time preferences for agricultural investment, and/or have the political power to influence the above factors that produce abnormal rents. Interaction between these multi-scale contextual factors and characteristics of agricultural production actors is key to understanding processes of agricultural frontier expansion by well-capitalized commodity producers.

The conceptual framework of pathways for commodity crop expansion (Meyfroidt et al. 2014) has been used in multiple contexts—ranging from Brazil, Indonesia, and Vietnam (Meyfroidt et al. 2014), Cambodia (Magliocca et al. 2019), Kazakhstan, Russia, and Ukraine (Meyfroidt et al. 2016), and sub-Saharan Africa (Ordway et al. 2017)—to study the multiple possible and contingent outcomes of increased commodity crop production. The commodity expansion pathways framework imposes an overarching structure of a series of cause-effect relationships (i.e., causal chains or pathways) leading to varying commodity crop expansion outcomes (e.g., agricultural intensification with land sparing; agricultural expansion into forests) with possible positive feedbacks and additional or indirect LUC. We adapt this framework (Fig. 1) to the context of Salta Province in northern Argentina to examine (1) how different combinations of multi-scale, causal factors and processes lead to different LSLA establishment and implementation pathways, and (2) whether/how those pathways differ from conventional commodity frontier expansion processes (i.e., non-LSLA agricultural parcels).

Meyfroidt et al. (2014) describe commodity crop expansion pathways as beginning with changes in land tenure entailing transactions between local, extra-local (e.g., national elites), or foreign actors, which in turn initiate a causal chain of events generating multiple possible pathways of commodity crop production and associated LUC outcomes. Each pathway is defined by a combination of causal factors and/or processes: (1) the attributes of the land transactions (e.g., timing of land tenure change, buyer origin, characteristics of the commodity crop), (2) contextual factors at local, regional, and global scales, and (3) the rate and extent of LUC associated with commodity crop production (Fig. 1). The first two components are wholly compatible with the characteristics of actors and causal factors,

respectively, that influence commodity frontier expansion proposed by le Polain de Waroux (2018). However, the pathways approach additionally emphasizes causal chains among these components as a key conceptual framing and unit of analysis. Thus, we integrate these frameworks with a spatially and temporally explicit analysis of the pathways of commodity crop expansion and resulting LUC in Salta province.

Fig. 1. Characteristics of land transactions and local, regional/national, and global contextual factors that can produce “abnormal rents” for commodity frontier expansion and create various causal pathways for land-use change. Adapted from Magliocca et al. (2019).

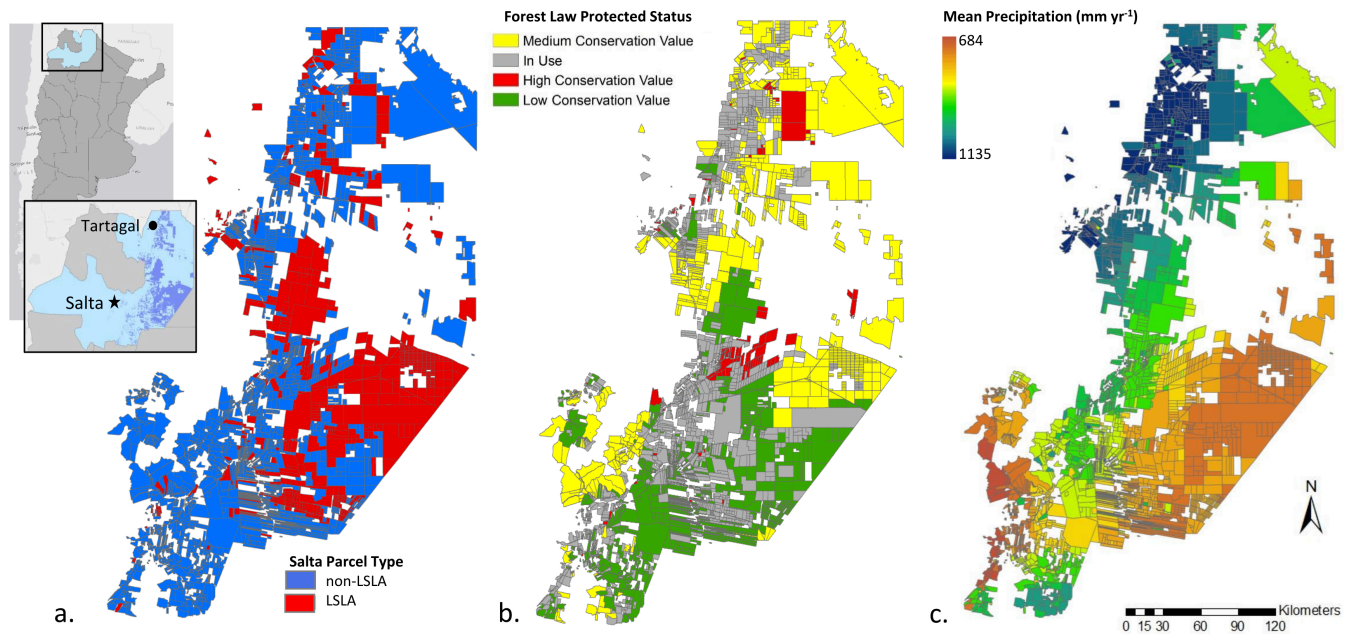


In Salta, like most of the Argentine Chaco, commodity crop production is not a new phenomenon. Changes in several contextual factors, originating both within and external to the region, have shaped recent commodity frontier expansion in Salta. We hypothesize that the actors catalyzing commodity frontier expansion post-2008 added new motivations to mobilize and invest capital in commodity frontier expansion to those operating previously in the region, and that this led to divergent LUC outcomes between LSLA and non-LSLA agricultural parcels. Specifically, the actors associated with LSLAs were drawn to investment in agricultural frontier areas by the unique confluence of several global macroeconomic and political trends. More pronounced and rapid increases in land (le Polain de Waroux et al. 2016) and commodity prices were observed post-2008 corresponding with simultaneous global financial and food crises, droughts in globally significant agricultural production regions, and increased competition for land for biofuel productions (Searchinger et al. 2008, Zoomers 2010). In particular, as real estate and financial markets collapsed, land became a more attractive option for international investors, leading to pressure on commodity prices and land acquisition in frontier regions (Galaz et al. 2015). Following this reasoning, LSLA actors may have had more non-production interests in acquiring land along the agricultural frontier, which translated into LUC outcomes divergent from those of non-LSLA actors. Specifically, we investigate whether LSLA and non-LSLA exhibit different timing and LUC trajectories, and whether they responded differently to the land-use controls implemented in the 2007 Forest Law.

METHODS

Our approach used survival analysis to estimate the influence of time-varying factors (e.g., commodity prices), relatively static conditions (e.g., soil properties), and contextual factors

Fig. 2. Maps of Salta province’s arable parcels (highlighted in dark blue in inset map) differentiated by (a) parcel type (i.e., large-scale land acquisition (LSLA)/non-LSLA), (b) protected status under the 2007 Forest Law, and (c) average annual precipitation. Only parcels with land acquisitions or observed land-use change since 2000 are shown and included in the analysis. State-owned lands in north-central Salta province—known as “Lotes 55 y 14”—and non-arable parcels were excluded from the analysis. Data sources are provided in Table 1.



associated with the land acquisition process (e.g., foreign investor) on the timing of LSLA establishment and LUC in both non-LSLA and LSLA parcels. In addition, specific survival probabilities were estimated for each category of conservation zoning in the Forest Law to differentiate land-use trajectories in response among non-LSLA and LSLA parcels.

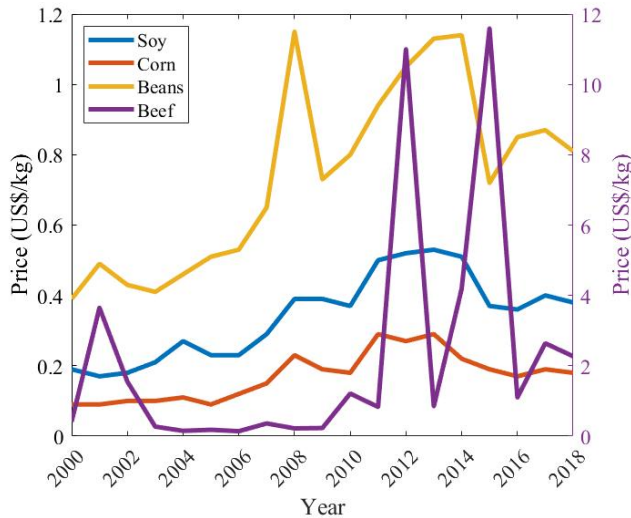
Study Region

Our study region encompasses the arable regions of Salta province in northern Argentina (Fig. 2), the majority of which is contained within the Dry Chaco ecoregion (Vallejos et al. 2015, Nolte et al. 2017) and used for crop cultivation and/or cattle ranching. The province is generally characterized by a west-to-east decreasing gradient in agricultural suitability, market access, and population density. Population and access to markets are concentrated in the western Salta, which corresponds with higher elevations, annual precipitation, and better growing conditions. Rural parcel size generally follows an increasing gradient from west-to-east, with the largest parcels located along the eastern agricultural frontier. Northern and eastern areas of Salta Province have been the focal points for substantial agricultural expansion and accompanying forest loss since the 1990s (Volante et al. 2016) and are home to numerous criollos and indigenous communities. These biophysical, socioeconomic, and sociopolitical gradients have historically shaped much of the LUC in Salta Province.

The conversion of vast parts of the Argentinian Pampas from livestock to farmland nearly 50 years ago drove initial expansion of extensive agricultural production and ranching to Salta (le

Polain de Waroux et al. 2018). Expansion of agriculture for export in the Argentine Chaco occurred before the global increase of LSLAs (late 1990s), and was primarily driven by domestic economic growth and the introduction of no-till agriculture and transgenic soy (1997–2002) that enabled soy cultivation in locations previously too dry (Gasparri et al. 2013, Volante et al. 2016). The west-to-east spatial patterns of agricultural expansion since the 1990s have been described as a “poorly selective contagion” process (Volante et al. 2016). Briefly, Volante and colleagues (2016: 154) described the advancement of the agricultural frontier into marginal areas in which socioeconomic and political factors became more important over time than agro-ecological conditions. Owing to technological advances and the availability of cheap, poorer-quality land on which to expand production, Salta’s once considered “marginal” lands sustained profitable soy and cattle operations. Additionally, currency devaluation in the early 2000s decreased production costs relative to export prices and incentivized investment in frontier agriculture (le Polain de Waroux et al. 2018). Similarly, beef, soy, bean, and maize commodity prices all spiked at various times after 2000 (Fig. 3), increasing producer prices and spurring agricultural expansion. Both past and contemporary commodity frontier expansion in Salta was/is fueled by cattle ranching and soy, and to a lesser extent white and black beans and maize. Also consistent between pre- and post-2000 commodity frontier expansion in Salta is the relative prominence of domestic investors, whether exclusively Argentinian or in joint ventures with transnational investors (Salas Barboza et al. 2019).

Fig. 3. Global commodity prices from 2000–2018 for the main commodities produced in Salta province. Prices in US\$ per kilogram are indicated on the y-axis for row crops (corn, soy, and white (i.e., “alubias”) beans) on the left and beef on the right. Sources: FAOSTAT 2019, Index Mundi 2019.



More recently, land governance has become a stronger influence on LUC. In November 2007, the government of Argentina responded to growing public concerns about deforestation with Federal Law 26331/2007. The “Forest Law” would regulate the protection, enrichment, restoration, utilization, and management of native forests and the environmental services they produce while also acknowledging the ancestral rights of indigenous and local communities. As a first step, the law required each province to carry out within 1 year a comprehensive and participatory land use planning process (LUPP) with respect to native forests (Seghezzeo et al. 2011), during which time no deforestation was authorized. During the first year, the LUPP was to zone the entire province according to a number of technical and social criteria (i.e., area and habitat, ecological links, regional integration, value, connectivity, conservation state, forest potential, agricultural potential, hydrological basins, and cultural aspects) and designate all areas not already in use (zoning category “In Use”) as belonging to one of the following categories (Fig. 2b): Category I (“Red”): high conservation value (no deforestation allowed); Category II (“Yellow”): medium conservation value (sustainable use, tourism, research allowed); and Category III (“Green”): low conservation value (deforestation and productive activities allowed) (Fig. 2b). The LUPP in Salta was beset by a series of challenges, as powerful economic and political actors sought to influence the process, different maps were proposed by different interest groups (i.e., environmental NGOs, agribusinesses, and politicians), and public participation of interested indigenous and local communities was frustrated. A first map proposed at the 1-year deadline was discarded, and a modified map was approved 2 years later, in December 2008. Claiming lack of participation, indigenous communities and criollo families filed and won a lawsuit in the National Supreme Court resulting in a moratorium

and provisional halt to deforestation in four departments of Salta. The turbulent process of defining how and which lands would be protected under the Forest Law continued for several more years as Provincial Decree 2211 of June 2010 allowed for land clearings located in “Yellow” and “Red” areas through “recategorization” when they could be technically justified, and Decree 3136/11 exempted such recategorization procedures from the requirement to submit to a public hearing (Leake et al. 2016). As a result of public pressure, these two decrees were struck down in 2014, but not before 32 properties were approved for “downgrading” from “Yellow” to “Green” without a public audience (Leake et al. 2016).

Units of Analysis

Parcel boundaries for all of Salta province were obtained from Infraestructura de Datos espaciales de la Provincia de Salta (IDESIA). Parcels were categorized as LSLAs by Land Matrix Latin America Focal Point and the Instituto de Investigaciones en Energía No Convencional (INENCO) using official cadaster obtained from the provincial cadastral office (Dirección de Inmuebles de la Provincia de Salta). Extracted data included (a) the date of the last transaction from the year 2000 onward (i.e., LSLA establishment), (b) type of transaction (purchase, sale, lease, or concession), and (c) the investor involved. This information was corroborated, if possible, with media reports or other types of secondary information sources. As defined by the Land Matrix initiative (see <http://www.landmatrix.org>), an independent global land monitoring initiative made up of global and regional partners, LSLAs were defined as land transactions that entailed a transfer of rights to external actors (i.e., buyers were not previous land owners in Salta Province) to use, control, or own land through sale, lease, or concession, covering 200 ha or more, and concluded since the year 2000 (Anseeuw et al. 2013a). Large-scale land acquisition boundaries were digitized using ESRI’s ArcGIS based on official records. Boundaries were scrutinized using Google Earth Pro high-resolution imagery as well as Landsat and Planet imagery in Envi and ArcGIS. The data were further “cleaned” to match cadastral boundaries with imagery, remove extraneous small (sliver) polygons, join multiple deal IDs, and remove duplicate deals.

Parcels >200 ha established prior to 2000 were excluded from analysis as the present analysis adheres to the Land Matrix definition of LSLAs (established after 2000, >200 ha) and thus the date of establishment (i.e., the first event of the causal pathway) was not observed. For the purposes of our analysis, non-LSLA parcels were defined as only those zoned as “Rural” in the official cadaster with observable LUC (forest conversion to pasture or cropland) since 2000, and not reported in the LSLA Land Matrix Latin America Focal Point data set. The date of LUC for non-LSLA parcels was determined using a hand-digitized data set of observed annual anthropogenic forest conversion in the Dry Chaco (Vallejos et al. 2015). The data set was created using visual interpretation of the spatial shapes of converted plots (e.g., regular shapes, hedgerows, etc.) from LandSat imagery to infer forest conversion to cropland and pasture with an overall classification accuracy of 97.8%. State-owned lands in north-central Salta province—known as “Lotes 55 y 14”—were excluded from the analysis because of their contestation as indigenous territory. Based on these criteria, the total number of non-LSLA and LSLA parcels included in the analysis was 2,754, which covered a total area of 4.854 million

Table 1. Descriptions and sources of variables use in survival analysis.

Name	Description	Units	Source
Dependent			
LSLA establishment	Year of land transaction (i.e., land ownership change for external investor)	Year	Land Matrix Latin America Focal Point
Land-use change	Year of land-use change, either removal of forest cover or change in cultivation patterns, observed within parcel boundaries. Initiation of a new land use within LSLA parcels was referred to as “implementation”	Year	National Agricultural Technology Institute (INTA 2012), (Vallejos et al. 2015)
Independent			
<i>Time-independent</i>			
Parcel dummy	Parcel identification number (control variable).	n/a	Infraestructura de Datos espaciales de la Provincia de Salta (IDESA) ¹
Parcel size	Size of land parcel	Hectares	IDESA
Average slope	Percent slope calculated from high resolution (~30 m) topographic data from the ASTER Global DEM	%	ASTER Global Digital Elevation Model V002 (NASA and METI 2019) ²
Percent mollisols	Percent of principle soil type of mollisols, indicator of the potential agricultural productivity of soils.	%	INTA (2012), Volante et al. (2016)
Precipitation	Annual average precipitation (0.25 X 0.25 degree)	mm yr ⁻¹	3B43 Tropical Rainfall Measuring Mission (TRMM) (Huffman et al. 2010)
Cost distance to market	Estimated average travel costs to provincial capitals based on existing road networks	USD (\$)	Piquer-Rodríguez et al. (2018)
Water accessibility	Distance (m) to rivers and wetlands	m	Instituto Geográfico Nacional (IGN) (2019) ³
Protected status (2009)	Protection categories as of 2009 established under the 2007 Forest Law (low, medium, and high conservation value corresponding to no, moderate, and permanent protection).		Infraestructura de Datos espaciales de la Provincia de Salta (IDESA)
Population density (2000)	Population density mapping product at ~ 1 km resolution	ppl km ⁻¹	Center for International Earth Science Information Network (CIESIN) - Columbia University (2018)
Crop yield (2000)	Average yield for maize	kg ha ⁻¹	Monfreda et al. (2008)
Forest cover (2000)	Percent forest cover (30m)	%	Hansen et al. (2013) ⁴
<i>Time-dependent</i>			
Commodity export value and quantity	Commodity prices for soy, corn, dried bean, and beef	\$ kg ⁻¹	Index Mundi (2019), FAO (2019)
Foreign Exchange Rate (2000–2018)	Annual average exchange rate from Argentine pesos to USD	Pesos	Federal Reserve Bank of St. Louis ⁵

¹ https://www.idera.gob.ar/index.php?option=com_content&view=article&id=335:geoservicios&catid=118:geoservicios&Itemid=302

² <https://dx.doi.org/10.5067/ASTER/ASTGTM.002>

³ <http://www.ign.gob.ar/NuestrasActividades/InformacionGeoespacial/CapasSIG>

⁴ https://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.6.html

⁵ <https://fred.stlouisfed.org/series/ARGCCUSMA02STM>

hectares (3.181 million hectares non-LSLA, 1.673 million hectares LSLA).

Variables

Both time-independent and -dependent (i.e., time series) variables were considered (Table 1). Time-independent variables included parcel characteristics influencing agricultural production, such as parcel size, annual precipitation, slope, proximity of surface water sources, and soil quality, and indicators of market accessibility, such as travel time and population density. Impacts of LUC on conservation outcomes were also considered by characterizing each parcel’s percent forest cover at the beginning of the study period (2000) and protection status category according to the 2007 Forest Law. Time-dependent variables included commodity prices for soy, corn, dried beans, and domestic beef and the foreign exchange rate between U.S. dollars and Argentine pesos. Collinear or cross-correlated variables were gradually removed for regression analysis until variance inflation factors were below 2 for all remaining variables. Not surprisingly,

commodity prices for soy, maize, and beans were strongly cross-correlated, and therefore, only prices for soy and beef were used in the analysis.

Rather than directly relating global commodity prices to observable LUC, simplified profit functions for each of the commodity crops considered were derived to isolate the effects of the relative differences in production costs due to location and the dynamic influences of prices and the exchange rate. Profit functions followed the general form in Eq. 1:

$$\pi_{c,i,t} = r_t Y_{c,i} P_{c,t} - C_i \quad (1)$$

where revenue R from production of commodity crop c in parcel i at time t was a function of the Argentine peso exchange rate (r), average yield (Y), crop price (P), and cost distance (C). The average maize yield was used to calculate profit functions for all commodity crops for three reasons. (1) Among the commodity crops considered, globally consistent, spatially explicit crop yield

data (Monfreda et al. 2008) were only available for rain-fed maize within our study area. (2) The survival analysis investigated the timing of land transactions and subsequent LUC, and we assumed that time-varying commodity prices and exchange rates would overwhelm any year-to-year fluctuations in crop-specific yields (Gasparri et al. 2013), and thus only relative changes among the more dynamic economic signals were input into the profit functions. (3) Cost–distance to the provincial capital (in USD), a spatially explicit indicator of accessibility to commodity markets on the basis of existing road networks (2010) and estimated average travel costs (Piquer-Rodríguez et al. 2018), was crop independent. The profit functions enabled a spatially varying estimate of the dynamic effects of commodity prices and exchange rate without requiring knowledge of the specific crop cultivated in each parcel at each time step.

Large-scale Land Acquisition Land-use Change Analysis

Time to observable LUC within each LSLA parcel boundary was derived from a land cover classification product produced at the Instituto Nacional de Tecnología Agropecuaria (INTA) (Vallejos et al. 2015). This data product was generated for 2001–2015 and included 22 types of land use and crop type spanning summer (December–February) and winter (June–August). The timing of LUC occurring in LSLA parcels from 2016–2018 was estimated with additional land-use classification and visual interpretation. Change from forest to another land use type was performed with visual interpretation of Landsat and PlanetScope imagery. To detect changes in crop type, a random selection of 200 centroids from each land-cover/use type ($n = 22$) were taken from all parcels. Following typical classification protocols, we used 70% of the sample points for training and 30% for validation. The points were imported into Google Earth Engine to conduct Random Forests classification on three Landsat composites for each year (2016, 2017, 2018). Composites were created for the summer period months and ensuring minimal cloud and cloud-shadow scenes.

Years of change for all LSLA parcels were verified using visual interpretation of Google Earth, Landsat, and Planet imagery, which demonstrated the high fidelity of the INTA data set for capturing the timing and extent of change within LSLA boundaries. As land clearing or cover change did not typically happen across entire LSLA polygons at once, inspecting the timing and extent of change within individual parcels offered more accurate estimates. In cases when the land was completely or partially altered before the date of LSLA establishment, only changes that occurred since the year of establishment were used in the survival analysis.

Supplementary Evidence

Field research in the summer of 2018 was conducted to aid and support our understanding, analysis, and conclusions. We collected ground-truth data for validation of LUC classification and conducted key informant interviews. Ground-truthing for selected LSLA plots was aided using a unmanned aerial vehicle (UAV) to collect high resolution imagery and GPS coordinates of parcel boundaries. Acquired imagery was used to verify reports of crop types or pasture land use, which in turn assisted our interpretation of satellite data, such as dense time stacks of Landsat and imagery in Google Earth Pro. Structured and unstructured interviews were conducted with regional

researchers, large-scale agricultural producers, and representatives of conservation groups. Interviewees described historical and current agricultural practices related to commodity crops, identified potential factors influencing the locations and timing of LSLAs, and articulated likely effects of the Forest Law on the previous two topics. The field campaign provided field verification of the observable changes from remote sensing and clarified understanding of the role and impacts of policy and LSLAs, producer motivations, and influence of markets.

Survival Analysis

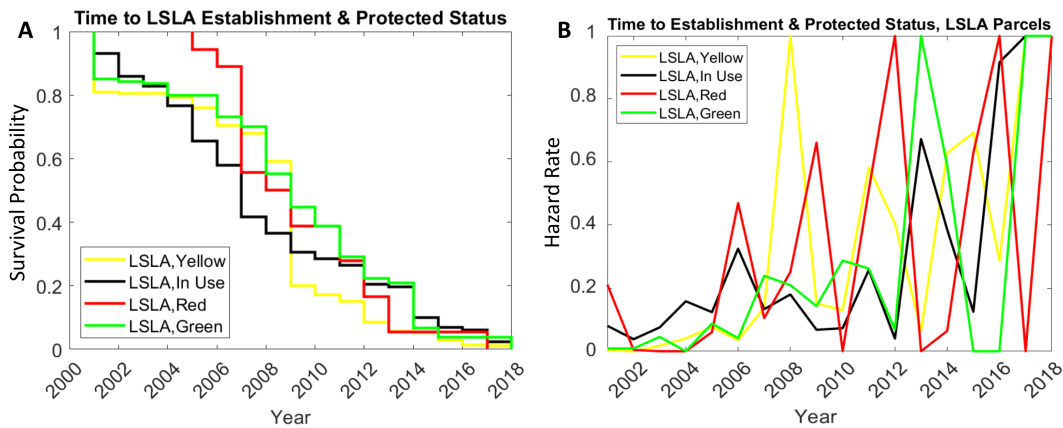
Survival analysis was conducted to estimate potential causal effects of local conditions and regional/global market signals on the timing of LSLA establishment and LUC among non-LSLA and LSLA parcels from 2000–2018. Survival analysis, also known as duration analysis or hazard modeling, estimates the time-varying probability of transition between two states (Vance and Geoghegan 2002, An and Brown 2008, Wang et al. 2013). In this case, the timing of transitions of interest were (1) a change in land ownership associated with a land transaction (LSLA parcels only), and (2) observable LUC in the form of forest clearing or change in land management (e.g., fallow to row crop; both LSLA and non-LSLA parcels). Unlike logistic regression, which does not effectively account for differences in the change of states at different points in the study period (Wang et al. 2013), survival analysis accounts for the effects of time-dependent (i.e., time series) covariates before and after a state transition relative to a base hazard rate. This makes survival analysis particularly well suited for establishing the sequence of events leading to a state change and for assembling causal chains or pathways of land transactions and subsequent LUC.

A survival analysis yielding time-varying survival probabilities and time-varying hazard rates was estimated for (1) time to LSLA establishment and (2) first LUC in both non-LSLA and LSLA parcels. A standard Cox Proportional Hazards model was estimated with the following form:

$$\log h_i(t) = \alpha(t) + \beta_1 X_{i1} + \beta_2 X_{i2} + \dots + \beta_k X_{ik} \quad (2)$$

where $h_i(t)$ is the hazard rate of parcel i at time t , $\alpha(t)$ is the baseline hazard rate (unobserved and implicitly estimated (An and Brown 2008)), and β_k are the coefficients estimating the relative contribution of k independent variables in listed in Table 1. Survival probabilities are the inverse of hazard rates and estimated for each parcel relative to the survival times of all other parcels. Survival probabilities indicated the probability of any given parcel changing its state (e.g., LSLA change from established to implemented) in a specified year relative to the number of state changes observed to that point among the total sample. Hazard rates were estimated from survival probabilities and provided a time-varying indicator of risk of state change given a parcel's characteristics and external pressures. Increased hazard rates in any given year signal higher probabilities of state change by the next year. For example, increases in the hazard rate for LSLA establishment preceded the year of the land transaction (Fig. 4b), whereas decreases in the survival probability of LSLA parcels (Fig. 4a), indicating a change in state (i.e., ownership), occurred the same year as the land transaction.

Fig. 4. Time-varying survival probabilities (a) and hazard rates (b) for establishment (i.e., land transaction and change of ownership) of LSLA parcels. Colors correspond to protection categories implemented in the Forest Law.



Additionally, fixed effect, stepwise regression was used to estimate the influence on survival probabilities of all time-independent and time-dependent variables listed in Table 1. To test the influence of different types of actors (i.e., LSLA vs. non-LSLA) and Forest Law protection status on LUC outcomes, parcels were stratified by pairwise combinations non-LSLA or LSLA and four Forest Law protection status categories. Due to a small sample size of LSLA parcels in the “Red” Forest Law category ($n = 14$), these parcels were combined with the LSLA parcels in the “In Use” category for regression analysis because: (1) median survival times were not statistically distinguishable using a Wilcoxon Rank Sum Test (p value = 0.6789); and (2) they displayed similar survival curves. To ensure that strata were statistically meaningful, pairwise log-likelihood tests were performed between stratified and unstratified model formulations to avoid over-specification. Comparisons of median survival times among strata were conducted to test the null hypothesis that survival probability between two groups was the same. Strata had statistically different survival probabilities in all pairwise combinations. Finally, robustness checks were performed with 1- and 2-year leading time-dependent variables to rule out spurious correlations. For both leading times, only the parcel dummy variable (which was time-independent) was statistically significant, indicating that significant relationships found with time-dependent variables hypothesized to influence LSLA establishment or LUC among all parcels, such as commodity prices, were meaningful.

RESULTS

Large-scale Land Acquisition Establishment

Hazard rates for LSLA establishment for “Yellow” and “Red” parcels (Fig. 4) spiked during 2006–2012, coinciding with the contested political processes surrounding implementation of the Forest Law. Approximately 40% and 60% of parcels in “Red” and “In Use” areas were established during the 7 years of the study period preceding initial passage of the Forest Law in 2007. “Red” parcels also demonstrated an elevated hazard rate for LSLA establishment in 2008–2009, leading to a 20% increase in LSLA establishment during that time. This was in contrast to roughly

30% or less of “Yellow” and “Green” LSLA parcel establishment by that time.

Based on regression results, increased risk of and hazard rates for LSLA establishment, regardless of Forest Law protection category, were strongly positively associated with increased commodity prices (Table 2). Increased hazard rates for LSLA establishment in “In Use” and “Green” areas followed increases in beef prices closely. Establishment of LSLAs was more likely on “Yellow” than all other parcels in response to beef and soy price increases. However, hazard rates of establishment spiked in 2008, coinciding with a spike in the price of beans, which was inferred based on the locations of LSLA establishment at that time coinciding with bean-growing regions of northern Salta Province around Tartagal. Biophysical factors and enforcement of the Forest Law combined to explain the remaining spatio-temporal patterns of LSLA establishment. Large-scale land acquisition parcels in the “In Use” and “Red” protected areas were disproportionately established early in the study period in locations with higher tree cover (Table 2) but were nearly 60% less likely over time in areas with higher population density. Roughly 30% of “Yellow” LSLA were established prior to the passage of the Forest Law. The hazard of LSLA establishment on “Yellow” parcels spiked in 2008, and by 2009, roughly 80% of all “Yellow” LSLA parcels were established. Large-scale land acquisition establishment on “Green” parcels generally occurred later in the study period, coinciding with establishment generally further east into the frontier. “Green” parcels with high precipitation areas were at risk early in the study period, however roughly 70% of LSLA establishment on “Green” parcels occurred in drier, frontier areas after 2009.

Large-scale Land Acquisition Implementation

Large-scale land acquisition implementation (i.e., LUC) was increasingly likely in lower population density areas with low slopes as time went on (Table 3). This LUC pattern was particularly pronounced among LSLA parcels in the “Yellow” and “Green” protection areas in the latter half of the study period. Precipitation was not an important factor influencing hazard rates, as LSLA parcels were generally established in drier areas in

Table 2. Survival analysis results for time to establishment of LSLA parcels. Hazard ratio (HR) estimates are provided with a 95% confidence interval (CI).

Variable	“In Use” (n = 209) + “Red” (n = 14)		“Yellow” (n = 253)		“Green” (n = 116)	
	Estimate	HR (95% CI)	Estimate	HR (95% CI)	Estimate	HR (95% CI)
Parcel dummy	0.0945	1.099 (0.675–1.79)	-0.1349	0.8738 (0.558–1.37)	-0.1056	0.9000 (0.447–1.81)
Parcel size (ha)	-3.784	0.0227 (2.5×10^{-4} –2.10)	1.922**	6.835 (1.35–34.7)	0.3523	1.422 (0.444–4.55)
Tree Cover (2000)	1.383***	3.987 (2.27–7.00)	0.0580	1.060 (0.316–3.56)	0.5274	1.695 (0.245–11.7)
Percent Mollisols	0.1166	1.124 (0.758–1.67)	0.0299	1.030 (0.654–1.62)	0.1346	1.144 (0.705–1.86)
Distance to water	-0.2834	0.7532 (0.285–1.99)	0.6057	1.833 (0.619–5.43)	0.1100	1.116 (0.173–7.19)
Population density	-0.9035***	0.4051 (0.225–0.729)	-0.5107	0.6001 (0.326–1.10)	0.2800	1.323 (0.540–3.24)
Slope	-2.017	0.1331 (0.001–16.1)	-0.6905	0.5013 (0.096–2.61)	0.3644	1.440 (0.006–354)
Precipitation	-0.1486	0.8619 (0.261–2.85)	-0.2113	0.8095 (0.202–3.24)	-3.842**	0.0214 (0.001–0.803)
Beef price	18.32***	9.0×10^7 (4.8×10^5 – 1.7×10^{10})	22.85***	8.3×10^9 (1.1×10^7 – 6.6×10^{13})	15.71***	6.6×10^6 (199 – 2.2×10^{11})
Soy price	114.5***	5.3×10^{49} (1.9×10^{35} – 1.6×10^{60})	126.1***	5.8×10^{34} (5.5×10^{42} – 6.0×10^{66})	118.0***	1.7×10^{21} (6.0×10^{34} – 4.7×10^{67})

Significance codes: “*” *p* value < 0.1; “**” *p* value < 0.05; “***” *p* value < 0.01

the eastern portion of Salta Province. Commodity price dynamics played a major role in frontier expansion as the risk of LUC was higher for all LSLA parcels in response to increased soy, maize, and bean prices (Table 3). Increased hazard rates for implementation among “Green” and “Yellow” LSLA parcels were aligned with the timing of beef price increases (Figs. 5a, 6). The period of beef price volatility in 2012–2015 was associated with rapid land conversion of more than 60% of all LSLA implementation observed in the “Green” category. Implementation remained under or near 10% until 2011, and then accelerated in 2012 (first spike in beef prices) and again in 2015 (second spike in beef prices). Spatially, these parcels also tended to occur in drier locations with poorer soils more suitable for livestock than row crop production. Implementation was more gradual for LSLA parcels in the “Yellow” protection category but exhibited a similar spike in 2015. However, more than 70% of the total number of LSLA parcels in the “Yellow” category remained unchanged through 2018 compared with detectable LUCs in more than 50% of “In Use,” “Red,” and “Green” parcels.

Fig. 5. Time-varying hazard rates for implementation of LSLA parcels (a) and first LUC within non-LSLA parcels (b). Colors correspond to protection categories implemented in the Forest Law.

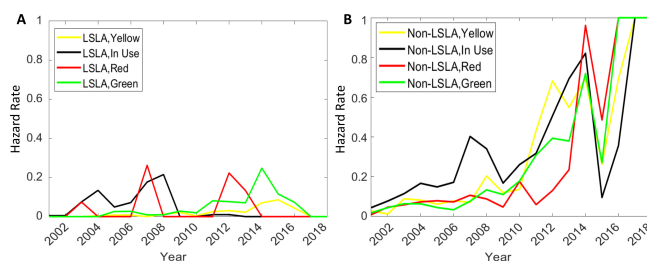
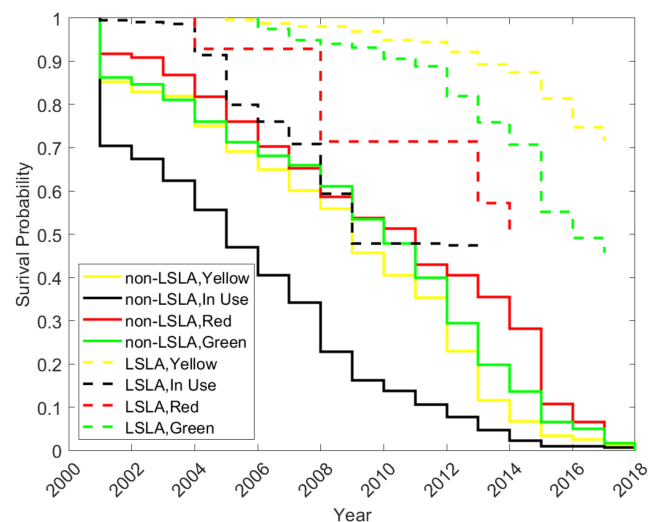


Fig. 6. Time-varying survival probabilities for implementation of LSLA and first LUC within non-LSLA parcels. Colors correspond to protection categories implemented in the Forest Law.



Similar to “Yellow” LSLA parcels, LSLA parcels in both “In Use” and “Red” categories showed heightened hazard rates through 2009. However, LSLA parcels in the “In Use” protection category, which tended to undergo LUC earlier in the study period (i.e., by definition in the LUPP of the Forest Law), did not respond to the same frontier expansion pressures as those in the “Green” and “Yellow” categories. Large-scale land acquisition parcels in the “In Use” category were generally located on higher quality agricultural land with better access to markets, coinciding with

Table 3. Survival analysis results for time to implementation (i.e., first LUC) of LSLA parcels. Hazard ratio (HR) estimates are provided with a 95% confidence interval (CI).

Variable	“In Use” (n = 209) + “Red” (n = 14)		“Yellow” (n = 253)		“Green” (n = 116)	
	Estimate	HR (95% CI)	Estimate	HR (95% CI)	Estimate	HR (95% CI)
Parcel dummy	-0.3188	0.7270 (0.375–1.41)	-0.3794	0.6843 (0.282–1.66)	-0.4687	0.6258 (0.242–1.62)
Parcel size (ha)	0.4388	1.551 (0.020–117)	2.083	8.029 (0.258–250)	0.4242	1.528 (0.198–11.8)
Tree Cover (2000)	0.3630	1.438 (0.718–2.88)	1.715	5.557 (0.643–48.0)	-0.4441	0.6414 (0.035–11.9)
Percent Mollisols	-0.0103	0.9898 (0.462–2.12)	0.2795	1.322 (0.325–5.39)	0.0984	1.103 (0.422–2.89)
Distance to water	0.6572	1.929 (0.495–7.53)	1.030	2.801 (0.480–16.3)	0.0093	1.009 (0.037–27.6)
Population density	-25.87***	2.1x10 ⁻¹² (2.1x10 ⁻²¹ –0.016)	-21.18	6.3x10 ⁻¹⁰ (4.4x10 ⁻²² –932)	-60.20**	7.1x10 ⁻²⁷ (1.3x10 ⁻⁵⁰ –0.004)
Slope	-12.03**	6.0x10 ⁻⁶ (5.7x10 ⁻¹⁴ –620)	2.819	16.76 (0.138–2.0x10 ³)	-26.83	2.2x10 ⁻¹² (3.2x10 ⁻³¹ –1.6x10 ⁸)
Precipitation	-0.4575	0.6329 (0.119–3.36)	0.7901	2.204 (0.127–38.4)	-0.2530	0.7765 (0.002–341)
Beef price	-11.04***	1.6x10 ⁻⁵ (8.6x10 ⁻⁹ –0.030)	23.05***	1.0x10 ¹⁰ (4.7x10 ⁷ –2.2x10 ¹²)	34.11***	6.5x10 ¹⁵ (1.8x10 ⁹ –2.3x10 ²⁰)
Soy price	325.9***	3.4x10 ¹⁴¹ (2.8x10 ¹⁰⁶ –3.9x10 ¹⁷⁶)	171.1***	2.0x10 ⁷⁴ (1.8x10 ⁵² –2.1x10 ⁹⁶)	303.9***	9.6x10 ¹³¹ (5.1x10 ⁷⁸ –1.8x10 ¹⁸⁵)

Significance codes: “*” *p* value < 0.1; “**” *p* value < 0.05; “***” *p* value < 0.01

slightly steeper slopes and closer proximity to population in western Salta. This was consistent with the trend that LSLAs in the “In Use” category were generally not implemented in these areas for beef production, as indicated by the deterrent effect on LUC within increased beef prices (Table 3). Nearly all LSLA parcels designated as “In Use” underwent implementation prior to the finalization of the Forest Law’s LUPP in 2010 (Fig. 5a). Notably, an additional 20% of LSLA parcels in the “Red” category, which were areas deemed high conservation value requiring permanent protection by the Forest Law, demonstrated at least some detectable LUC in 2012–2014—after their protection status was set.

Non-large-scale Land Acquisition Implementation

Non-LSLA parcels tended to be located on better agricultural land (e.g., higher precipitation) and underwent LUC earlier (i.e., shorter survival times) than LSLA parcels (Fig. 7). This was true for non-LSLA parcels in all protection categories (Table 4). This effect was strongest in “Red” and “Green” parcels, with both areas experiencing high conversion rates early and moderate conversion rates later in the study period as the agricultural frontier progressed into drier areas. Over the entire study period, “Red” and “Green” parcels were more than 90% less likely to experience LUC in drier areas early in the study period compared with 67% to 75% less likely for “In Use” and “Yellow” protected areas (Table 4). Higher population density was also a strong deterrent of LUC as time went on in “In Use” and “Green” areas. This reflected relatively earlier LUC among non-LSLA parcels on better agricultural land and in more populated locations, and the advancement of the agricultural frontier into less populated areas over time. The opposite was true for soil type, measured by the percentage of mollisols (grassland ecosystem soils) within a parcel, which had no discernable effect on parcels in “In Use” or “Green” status. Parcels in “Red” protected areas with high mollisol content were more than twice as likely to experience LUC,

whereas parcels in “Yellow” protected status with high mollisol content were about 33% less likely to experience change. Slope was negatively correlated with probability of LUC within “Green” protected area parcels associated with later conversion in the flattest areas.

Fig. 7. Comparison of median survival times between non-LSLA and LSLA (i.e., time to first LUC or implementation, respectively) among each protected status category. Median values are indicated with red horizontal lines, boxes demarcate the first and third quartiles, and outliers are marked with ‘+’ symbols.



Table 4. Survival analysis results for time to implementation (i.e., first LUC) for non-LSLA parcels. Hazard ratio (HR) estimates are provided with a 95% confidence interval (CI).

Variable	“In Use” (n = 1,078)		“Red” (n = 121)		“Yellow” (n = 388)		“Green” (n = 575)	
	Estimate	HR (95% CI)	Estimate	HR (95% CI)	Estimate	HR (95% CI)	Estimate	HR (95% CI)
Parcel dummy	-0.0803	0.9228 (0.748–1.139)	-0.0301	0.9703 (0.479–1.97)	0.0951	1.100 (0.766–1.58)	0.0529	1.054 (0.789–1.41)
Parcel size (ha)	12.23***	2.0x10 ⁵ (1.91–2.2x10 ⁸)	23.96***	2.5x10 ¹³ (1.1x10 ⁴ –6.0x10 ¹⁶)	1.076	2.933 (5.1x10 ⁹ –1.7x10 ⁹)	15.08	3.5x10 ⁶ (2.1x10 ⁴ –9.6x10 ¹⁵)
Tree Cover (2000)	0.0571	1.059 (0.868–1.29)	0.1720	1.188 (0.389–3.63)	-0.1073	0.8983 (0.471–1.71)	-0.0902	0.9137 (0.515–1.62)
Percent Mollisols	0.1322	1.141 (0.844–1.54)	0.6959*	2.006 (0.883–4.55)	-0.4205	0.6567 (0.395–1.09)	0.0160	1.016 (0.715–1.44)
Distance to water	-0.0353	0.9653 (0.646–1.44)	0.8866	2.427 (0.533–11.0)	-0.1945	0.8232 (0.476–1.42)	0.2172	1.2423 (0.639–2.42)
Population density	-7.588***	0.0005 (6.2x10 ⁻⁶ –0.041)	-6.272	0.0019 (8.9x10 ⁻¹¹ –4.0x10 ⁴)	-1.254	0.2854 (0.052–1.58)	-9.682***	6.2x10 ⁷ (1.5x10 ⁻⁷ –0.026)
Slope	-0.6398	0.5035 (0.039–7.12)	-1.430	0.2393 (5.3x10 ⁻⁶ –1.1x10 ⁴)	0.1947	1.215 (0.406–3.64)	-3.213***	0.0402 (0.004–0.423)
Precipitation	-0.8646***	0.4212 (0.244–0.729)	-2.430***	0.0880 (0.014–0.546)	-1.395***	0.2478 (0.103–0.595)	-3.024***	0.0486 (0.016–0.146)
Beef price	14.48***	1.9x10 ⁶ (7.4x10 ³ –5.1x10 ⁸)	31.59***	5.2x10 ¹³ (1.4x10 ⁹ –2.0x10 ¹⁸)	26.95***	5.1x10 ¹¹ (1.7x10 ⁹ –1.5x10 ¹⁴)	27.90***	1.3x10 ¹² (2.1x10 ¹⁰ –8.3x10 ¹³)
Soy price	191.6***	1.6x10 ^{83a} (1.3x10 ⁷⁴ –2.1x10 ⁹²)	303.7***	7.8x10 ¹³¹ (1.3x10 ⁹⁰ –4.4x10 ¹⁷³)	256.8***	3.4x10 ¹¹¹ (5.4x10 ⁹¹ –2.0x10 ¹³¹)	271.0***	4.9x10 ¹¹⁷ (8.8x10 ¹⁰¹ –3.0x10 ¹³³)

Significance codes: “*” *p* value < 0.1; “**” *p* value < 0.05; “***” *p* value < 0.01

Parcel size did not have a statistically significant effect on hazard rates over time in “Yellow” and “Green” protection areas. The lack of a parcel size effect was surprising as those parcels tended to be larger, were converted later in the study period, and were zoned to encourage production. Conversely, parcel size was positively related to non-LSLA parcel LUC risk in “In Use” and “Red” protection categories, and the hazard of LUC increased as time progressed. This relationship was expected for parcels in the “In Use” areas, as the Forest Law did not preclude LUC. In fact, LUC among “In Use” parcels was particularly pronounced in 2007–2008, with a concurrent spike in hazard rate in 2006–2007 (Fig. 5b), and the largest annual increase in LUC events for “In Use” parcels in 2008 (Fig. 6). However, this relationship was not expected in “Red” protection areas, as the Forest Law explicitly prohibits LUC in these areas. The hazard of LUC in “Red” parcels also increased markedly in 2014, resulting in a 20% increase in “Red” parcels with observed LUC by 2015.

Finally, beef and soy prices (which were cross-correlated with prices for maize and beans) were strong drivers of LUC in all non-LSLA parcels. Increases in hazard rates were strongly correlated with spikes in commodity prices. In particular, “In Use” parcels experienced a roughly 20% increased hazard from 2007–2008, corresponding with higher soy, maize, and bean prices. Additional increases in “In Use” parcel hazard rates occurred in 2014 and 2017, corresponding with increased bean and soy prices. All other parcels experienced increased hazard rates (and subsequent decreased survival the following year) in 2012, 2014, and 2016–2017, corresponding with higher beef prices

Similarities and differences in the locations and dynamics of LUC among LSLA and non-LSLA parcels can be interpreted through three main themes: (1) Spatio-temporal patterns of regional LUC were consistent with commodity frontier expansion and a “poorly selective contagion” process; (2) heterogeneity among agricultural investment actors and within actor portfolios contributed to divergent land-use trajectories; and (3) mixed evidence of the

effectiveness of the Forest Law can be reconciled by considering investor heterogeneity.

Regional Spatio-temporal Patterns of Land-use Change Among Large-scale Land Acquisition and Non-large-scale Land Acquisition Parcels

Multi-decadal patterns of LUC in Salta’s Dry Chaco region follow the established commodity frontier expansion paradigm: expansion proceeded from high to low gradients in precipitation, population density, and soil suitability (% mollisols) and low to high initial tree cover. Regression results further reinforced the crucial role of commodity-oriented agriculture in frontier expansion. Following the commodity frontier expansion framework (le Polain de Waroux et al. 2018), elevated producer prices from increased demand for agricultural commodities created “abnormal” rents that spurred frontier expansion. Commodity price dynamics were associated with punctuated periods of LSLA establishment and LUC among LSLA and non-LSLA plots. Furthermore, the timing and locations of LSLA establishment and LUC dynamics were linked to price dynamics for specific commodity groups. Both LSLA and non-LSLA parcels in “Yellow” and “Green” protection categories tended to dominate in the lowest quality agricultural areas in the East, and their LUC dynamics were better aligned with price variations for beef than row crops. The parcels in the northern region of Salta Province around Tartagal, which had a large portion of parcels zoned as “Yellow” due to their proximity to existing indigenous settlements, were an exception to this pattern due to the prevalence of row crops (e.g., beans) with higher precipitation in the region.

Our results were consistent with the description of regional LUC dynamics in the Argentinian Dry Chaco advanced by Volante et al. (2016) as a “poorly selective contagious advance.” This was evident in the earlier conversion times (i.e., shorter survival times) for all non-LSLA parcels, whereas LSLAs were generally established later in the study period and implemented on parcels

with poorer agricultural conditions and more remote locations. However, the “poorly selective contagion” (Volante et al. 2016) explanation does not account for observed differences in local commodity expansion pathways between LSLA and non-LSLA parcels despite the same macroeconomic pressures and agro-ecological setting. Non-LSLA parcels in “Green” and “Yellow” areas had higher hazard rates in response to increased commodity prices than LSLA parcels in the same protection categories. Non-LSLA parcels in “Yellow” areas were the second (only to “In Use” parcels) fastest to convert, but LSLA parcels in the same protection category were the slowest to be implemented among all LSLA parcels. Large-scale land acquisition parcels in the “Yellow” areas demonstrated longer survival times than “In Use” parcels (Fig. 6), and diverged with the survival times of LSLA parcels in “Red” and “Green” protected areas toward the end of the study period (Fig. 6). Finally, only 5% ($n = 135$) of all parcels ($n = 2,754$) were assigned the “Red” protection category, and only 10% ($n = 14$) of “Red” parcels were LSLAs. After implementation of the Forest Law, 70% of the non-LSLA parcels in the “Red” protection category underwent at least some detectable LUC, whereas only 20% of “Red” LSLA parcels were implemented (Fig. 6). A closer look at heterogeneity among the agricultural investment actors and their motives using LSLAs as a focused “case set” through which to consider commodity frontier dynamics is an important area for future research in order to explain these differences.

Actor Heterogeneity and the Role of Land Speculation in Mediating Land-use Change Trajectories in Salta

Far less LUC was observed within LSLA parcels than non-LSLA parcels over the study period. Presence of longer lag times from LSLA establishment to implementation were likely due to some degree of speculation by LSLA actors. For example, one common agribusiness strategy used in Salta aims to maximize the value of agricultural assets as real estate—rotating the portfolio of properties over time, purchasing properties estimated to have high potential for appreciation, and selling them selectively as opportunities arise to realize attractive capital gains.^{1,2} Roughly 70% of LSLA parcels in “Yellow” protected status areas were unchanged (Fig. 6), suggesting that these could be the target of such speculation given the timing of their establishment (80% between 2000–2009, with half of that from 2008–2009) and relatively muted response to commodity prices after 2009. Large agribusiness companies operating throughout Latin America and with holdings in Salta increasingly evidence this kind of long-term, diversified portfolio investment strategy in which the initial phase of investment involves leaving land idle. However, profit-seeking strategies pursued by firms operating in Salta are diverse. Following initial acquisition of “under-utilized” properties, lands owned by larger local or extra-local (domestic, regional, or foreign) actors may follow all or some part of the following trajectory: investment in land improvements (i.e., clearing, construction of roads, fences, watering systems, improved herds, irrigation equipment and machinery, and even telecommunications service); transformation of “non-productive” land into cattle-feeding land; development of land suitable for more highly productive agricultural uses with improved agricultural technologies; or operation of the complete livestock cycle, yielding the highest market prices. Within a LUC trajectory associated with a specific parcel or set of parcels, actors at each

stage can remain one and the same, carrying out all phases of the property development from clearing to diversified production portfolios of cattle, soy, bean, etc. Alternatively, firms may participate in just one or more steps of land transformation (e.g., initial clearing of native forest or “improving” land for sale).

Differential Effects/Effectiveness of the Forest Law

Our findings offer a more nuanced understanding than current research into the effectiveness of land use governance in the Dry Chaco. Using statistically matched control and treatment parcels across each Forest Law protection zone and a difference-in-difference design, Nolte et al. (2017) found that the Forest Law had statistically significant effects on reducing overall rate of forest loss. Yet, findings that the Forest Law was effective in Salta Province have been criticized based on the observation that forest loss continued in all protection zones. In particular, forest clearing has been observed in “Red” zones (Volante and Seghezzo 2018), which constitutes illegal clearing and lack of enforcement of environmental laws by national and provincial administrations (Vallejos et al. 2021). Overall, the Forest Law was much more effective at limiting LUC among LSLA than non-LSLA parcels, as observed in the large proportion of LSLA parcels that did not proceed to implementation. However, there are important insights to be gained by considering the temporal dynamics and overall LUC trajectories of LSLA and non-LSLA parcels explicitly.

Whereas claims of subnational policy effectiveness are generally true across the region, the policy had differential effects depending on the land use actors involved. Restrictive land use zoning inevitably inhibits land use by some actors while promoting it among others (e.g., Magliocca et al. 2012). In the case of Salta, the Forest Law was effectively navigated by well-connected actors who were able to quickly mobilize capital and/or influence the land governance process. Prior to approval of the Forest Law in late November 2007, rapid LSLA establishment and preemptive LUC among both LSLA and non-LSLA parcels were observed as land owners and producers rushed to secure clearing permits³ (Seghezzo et al. 2011, Leake et al. 2016) (Figs. 4, 5). During the 2007–2009 “planning” phase of the Forest Law, spikes in establishment and LUC hazards were particularly pronounced for parcels in the more restrictive “Yellow” and “Red” areas. In later phases, the contested passage and implementation of the Forest Law, with its multiple rounds of litigation and revisions, map well with survival rates among both LSLA and non-LSLA properties in Salta. For example, the increase in conversions of “Yellow” and then “Red” parcels (particularly in 2013–2014) corresponds with the period between 2010 and 2014 when two decrees, Decree 2210, authorizing “recategorization” whereby owners could apply for land clearing permits in “Yellow” and “Red” areas when these could be “technically justified,” and Decree 3136, exempting the recategorization procedures from the requirement to submit to a public hearing, resulted in the eventual “downgrading” of 32 properties covering 145,000 ha to lower conservation values (Leake et al. 2016). Although initially the Law may have increased investment risk perception, potentially discouraging or delaying investment particularly if such investment could potentially result in increased operating costs (e.g., requirement for integrated silvopastoral grazing practices in 2015), influential investors were able to change Forest Law zoning.

Additionally, the Forest Law unintentionally selected for well-capitalized, large-scale actors that could pursue economy of scale agriculture in marginal land and hold land for non-production investment purposes. Many of the areas designated as “Yellow” or “Green” were feasibly farmed by only large-scale farms, which supported continued LUC among LSLA and non-LSLA parcels alike after the finalization of the Forest Law. The Forest Law demonstrably delayed LUC caused by LSLAs, but its ineffectiveness in slowing LUC in non-LSLAs parcels demands further research. Differences between LSLA and non-LSLA in LUC trajectories in response to the Forest Law likely relate to heterogeneous motivations among actors, such as production for domestic consumption (beef) vs. transnational investors placing a higher priority on land speculation as an investment strategy. If such differences related to investment actors among LSLA and non-LSLA parcels are not considered, this explains why there is a statistical signal detectable through causal inference methods that suggests effective limitations on forest loss, but further supporting counter narratives about the failure of the Forest Law to stop environmental degradation. Further research is needed to obtain a fuller understanding of the heterogeneity in motivations and business strategies of land investors.

South American Commodity Frontier Transformations, Shared Characteristics with Large-scale Land Acquisitions Globally?

In several respects, the pattern of establishment of LSLAs in Latin America and Argentina in particular, align with global trends. Although LUC change for large-scale agricultural production in the Chaco is well documented throughout the 1980s and 1990s (Volante et al. 2016, Baumann et al. 2016, 2017, Piquer-Rodriguez et al. 2018), rapid agricultural expansion by 2008–2009 was a response to unusual macroeconomic conditions—including the collapse of financial and real estate markets, and the resulting shift in global investment attention to agricultural land as a portfolio investment, as investors sought alternative, and more secure, places to put their money [e.g. retirement funds such as the Teachers Insurance and Annuity Association of America (TIAA) (Romero 2015)]. Such dynamics have similarly driven land acquisitions across Latin America (Venencia et al. 2019). However, our research suggests that actor motivations to expand agricultural production are better explained through a multifaceted lens where, even as land is treated as a financial asset, large new farmland managers and agribusiness owners continue to value it as a factor of production. Taking this view, the financialization of farmland going beyond “speculation” and in accordance with the commodity frontier hypothesis would also suggest increased LUC pressure for the following reasons. First, it is possible to use land productively while simultaneously speculating on financial returns from its appreciation, a “value of both farm and land” approach (Fairbairn 2014). Second, changes within the farmland investment sector— as is the case in South America— where land concentration has made it possible for operators to own hundreds of thousands of hectares, has resulted in the emergence of new farmland managers from the financial sector and from within agribusiness itself. Operating across multiple production sectors and locations (Gasparri and le Polain de Waroux 2015), such actors are connected through complex chains of ownership, operation, and financialization as “farmland investment management operations” (FIMOs), driving land improvement, production, and commercialization.

To the extent that LSLAs act as catalyst of commodity frontier expansion, they operate under similar logics of production and accumulation.

Limitations

Globally, research on LSLAs is continually challenged by data quality and completeness (Liao et al. 2016, Davis et al. 2020), which was also a concern across all of our analyses. Although data provenance was high, the process for collecting records of LSLAs and designating them as such was subject to a number of uncertainties. Large-scale land acquisitions were identified by the Latin America Focal Point of the Land Matrix by processing local cadastral information, analyzing websites and reports of all potential investors, cross-referencing the scientific literature on land investments, and monitoring and processing of local news sources and social media. Comprehensive accounting for investments within a given region remains a central challenge of the Land Matrix globally. Conclusions about the differential land-use trajectories among non-LSLAs and LSLAs must therefore remain tentative and subject to revision if more non-LSLA parcels were able to be identified as LSLAs. Despite these challenges, Salta province, and the Chaco region in particular, is one of the most researched spots for LSLAs globally (Salas Barboza et al. 2019). Therefore, the LSLA database used is considered relatively comprehensive and capable of providing a reliable picture of the phenomenon in the region.

In addition, data availability was uneven between LSLA and non-LSLA data sets. Assignment of specific crops to individual parcels would enable better discrimination of commodity price effects, although serial correlation among maize, beans, and soy would make this difficult. However, the overwhelming influence of commodity prices in all of the analyses diminished the importance of this limitation. Also, due to the targeted nature of the LSLA data set, information about actors’ origins and intended uses was available, whereas no such information was available for non-LSLA parcels. Due to these discrepancies between data sets, we chose the most conservative stratification for the survival analysis, comparing parcels designated as LSLAs with those not, rather than more specific nuanced parcel attributes like crop type, because a comparable analysis would not have been possible for non-LSLA parcels.

Finally, survival analysis is a data-demanding test of time-varying causal effects. For some time-independent variables, such as population data and Forest Law protection zoning, only cross-sectional data for a single year was available. Population movements toward or away from the agricultural frontier would have been a useful proxy of labor supply and/or displacement, which could have improved inference on the timing of LSLA establishment and implementation. With regard to Forest Law protection zoning, only one spatially explicit data set was available, yet we know that specific parcels were re-zoned through a politically contentious process. Our conclusions about differential LUC trajectories between Forest Law protection categories should thus be considered broadly applicable generalizations rather than predictors of any specific case. For other time-dependent variables, such as annual precipitation and forest cover, time series data were available, but we chose to use static values for the beginning of the study period to ease interpretation of time-varying hazard rates and survival

probabilities and isolate the dynamic effects of commodity prices. Although we conducted robustness checks (i.e., leading variables for survival analysis), the omission of potentially explanatory variables because of data limitations remains an area for improvement.

CONCLUSIONS

The Argentine Chaco is at the intersection of two globally significant trends in agricultural land-use change: expanding commodity frontiers and LSLAs. This analysis demonstrated similar spatial patterns of agricultural expansion in Salta Province that conformed to broader “poorly selective contagion” (Volante et al. 2016) trends throughout the Dry Chaco. However, consistent with the framework of commodity frontier expansion (le Polain de Waroux et al. 2018), the importance of heterogeneity among land investors was clear for understanding distinct LUC trajectories between LSLA and non-LSLA parcels. Unlike other recent multi-country assessments of spatial patterns of forest loss caused by LSLAs (Liao et al. 2020, Davis et al. 2020), the categorical consideration of actor heterogeneity and land transaction and LUC dynamics in this analysis provides a more nuanced understanding of their causes and possible outcomes. Full accounting and navigation of possible trade-offs that LSLAs may present policy makers is only possible when the level of explanation of LSLA outcomes matches that of the causal processes (Magliocca et al. 2018). In the case of LSLAs, individual actors’ unique capabilities and motivations to respond to land-use interventions will ultimately determine the effectiveness of such interventions. For example, land investors may have differential capabilities to respond and/or be resilient to volatile commodity prices, such as agroforestry cattle ranchers in Salta or rubber plantations in Cambodia (Magliocca et al. 2019, 2020). These differential capabilities can result in varying spatio-temporal outcomes—including rapid LSLA establishment and implementation, speculative investment with no LUC, and failed LSLAs with partial or no implementation—for the same investment type in the same region. As we demonstrated here for Salta, the Forest Law was a policy response to increased expansion of large-scale agriculture, but it had an uneven impact on LUC processes by benefiting some land investors more than others. Large-scale land acquisition research must move beyond large-scale, aggregate spatial assessments of outcomes that “black box” actors, and explicitly account for the role of heterogeneity among land investments as part of the causal mechanisms that influence land acquisition and use to more comprehensively inform policy.

^[1]The Nasdaq traded Argentinian agribusiness company, CRESUD, seeks to maximize return on assets and overall profitability by “identifying, acquiring and operating agricultural properties having attractive prospects for increased agricultural production and/or medium or long-term value appreciation and selectively disposing of properties subsequently as appreciation is realized. https://www.cresud.com.ar/compania-nuestra-estrategia-de-negocio_inst.php?lng=en accessed 26 April, 2020.

^[2]Field interview, May 21, 2018.

^[3]Proyectos de Cambio de Uso del Suelo (PCUS) or Projects for Land Use Change

Responses to this article can be read online at:

<https://www.ecologyandsociety.org/issues/responses.php/13103>

Acknowledgments:

The authors acknowledge support from NASA ROSES Land Cover Land Use Change (LCLUC) project award #NNX17AI15G. This study also contributes to the Global Land Programme (<https://glp.earth>).

Data Availability:

The data/code that support the findings of this study are openly available in The Land Matrix at <https://landmatrix.org/>, ILC, CIRAD, CDE, GIGA, and GIZ (2018).

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