Received: 15 July 2020 | Revised: 4 January 2021 | Accepted: 16 January 2021

DOI: 10.1111/conl.12794

Conservation Letters
A journal of the Society for Conservation Biology
Open Access
WILEY

LETTER

Land privatization and deforestation in a commodity production frontier

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Funding information
Lanscape Research Group

Abstract

Conservation policies often promote land privatization to reduce incentives for deforestation. However, empirical evidence on the relationship between land-tenure form and forest conservation outcomes is inconclusive. We combined key informant mapping and geospatial analyses to test the association between the area under tenure and the area deforested by extra-local private and local non-private agents in the Argentine Dry Chaco over four decades (1976–2016). The study area is a typical commodity production frontier within a global deforestation hotspot. We found a strong spatial and temporal coupling between the area under tenure and the area deforested by extra-local private agents from 1987 to 2006, when a 59% increase in the former was accompanied by a 508% increase in the latter. Local private agents maintained high levels of forest cover, similarly to local nonprivate agents. Our findings have implications for the adaptive design of the Forest Law in the Argentine Dry Chaco.

KEYWORDS
access, cattle, Chaco, dry forests, forest conservation, land tenure, land-use, private land, South America, soybean

1 | INTRODUCTION

Globally, policies and governance actions have not been effective at reducing commodity-driven deforestation (Curtis et al., 2018). Increasing the effectiveness of antideforestation governance requires context-specific knowledge about deforestation drivers (Reydon et al., 2020; Volante & Seghezzo, 2018). However, research on deforestation drivers has mostly focused on macroscale factors that are exogenous to the agents and institutions that determine governance outcomes (Rudel, 2006). Mesoscale analyses uncovering how particular agents access forest lands and make land-use decisions are a promising avenue for identifying leverage points for effective antideforestation governance (Jepson et al., 2010; Meyfroidt et al., 2014). Particularly, knowing how land-tenure changes relate to forest cover is a key input for such endeavor (Robinson et al., 2018).

Existing evidence on the relationship between land-tenure form and forest conservation is mixed and inconclusive, while the influence of land-tenure security is clearer (Robinson et al., 2014). Insecure land tenure has long been associated with higher deforestation (Araujo et al., 2009). Conservation policies have promoted land privatization to increase land tenure security, and thus stimulate investment in land-use practices that raise land productivity and reduce the need to clear forests (Wren-Lewis et al., 2020). However, deforestation in private lands can be similar or even higher than in public or communal lands (e.g., Paneque-Gálvez et al., 2013), when more secure tenure encourages greater investment in agricultural expansion (Busch & Ferreti-Gallon, 2017). Insecure land tenure, in turn, can be associated with forest maintenance, when the attitude, social norm and/or capital availability of land-users discourages forest conversion (Mastrangelo et al., 2014). Therefore, land privatization may not be associated with lower deforestation due to characteristics of the regional context and the agents involved (Probst et al., 2020). Empirical tests of this hypothesis are hard to undertake in countries where land-tenure data at relevant spatial and temporal scales is often absent or inaccessible.

Commodity production frontiers, such as those formed by the expansion of soybeans in South America and oil palm in Southeast Asia, are places where agents, institutions and ecosystems change rapidly (Meyfroidt et al., 2014). Broadly speaking, State-led agrarian reforms and colonization programs enabled frontier expansion by smallholder farmers during the 1960s and 1970s (Rudel et al., 2009). From mid-1980s, neoliberal policies and the retreatment of the State from rural lands enabled frontier expansion through large-scale deforestation by capitalized farmers (Rudel & Hernandez, 2017). In contemporary commodity frontiers, context-specific knowledge of the dynamic interactions between agents and institutions is key to develop targeted and tailored conservation policies. However, high levels of social heterogeneity and conflict have hindered an accurate attribution of responsibility for deforestation to particular agents and institutions. Few existing studies have done so by combining cadastral maps, census information and remote sensing (e.g., Godar et al., 2014) but have defined agents based on attributes of the landholding (e.g., size) rather than the land-user (e.g., identity). Assessing the interaction between land-tenure forms and land-user types on a scale of decades is thus key to identifying the mesoscale drivers of deforestation in commodity frontiers.

The Argentine Dry Chaco has displayed in the last four decades a dynamic illustrative of other South American regions oriented to export commodity production, such as the Brazilian Cerrado, the Bolivian Chiquitania, and the Paraguayan Chaco (le Polain de Waroux et al., 2017). In this region, indigenous and peasant populations have long settled on public lands and developed livelihood strategies that depend on goods and services supplied by native ecosystems. These land-users have been claiming land possession rights and some have obtained them in the form of pretitles or possession titles (Rudel & Hernandez, 2017). Such titles do not confer land-tenure security to local land-users, rendering them prone to land dispossession (Caceres, 2015; Goldfarb & van der Haar, 2015). By the end of the 20th century, a combination of macroeconomic, technological and climatic changes stimulated the arrival to the Argentine Dry Chaco of soybean farmers, cattle ranchers and land investors from richer neighboring regions, especially the Humid Pampas (Krapovickas, 2010; Paolasso et al., 2012a). In the absence of a State-led land-tenure reform, market signals (i.e., commodity and land prices) encouraged extra-local newcomers to acquire large tracts of lands with pristine soils to cultivate soybeans and/or pastures, by either (i) buying land possession rights from peasant families at very low prices, or (ii) using their higher power to displace possessors through violence (Busscher et al., 2019). Once extra-local agents got the possession of these lands, employed their economic and political power to obtain property titles (Goldfarb & van der Haar, 2015). This process triggered rapid changes in land-tenure forms and land-user types, whose impacts on forest conservation have not been assessed yet.

Here we assess the influence of local land-users with nonprivate land possession and extra-local land-users with private land ownership on deforestation over four decades (1976–2016) in the Northeast of Santiago del Estero province, Argentina. This area is a typical commodity production frontier within a region identified as a global deforestation hotspot from 2000 to 2012 (Hansen, 2013). Deforestation rates in the Northeast of Santiago del Estero

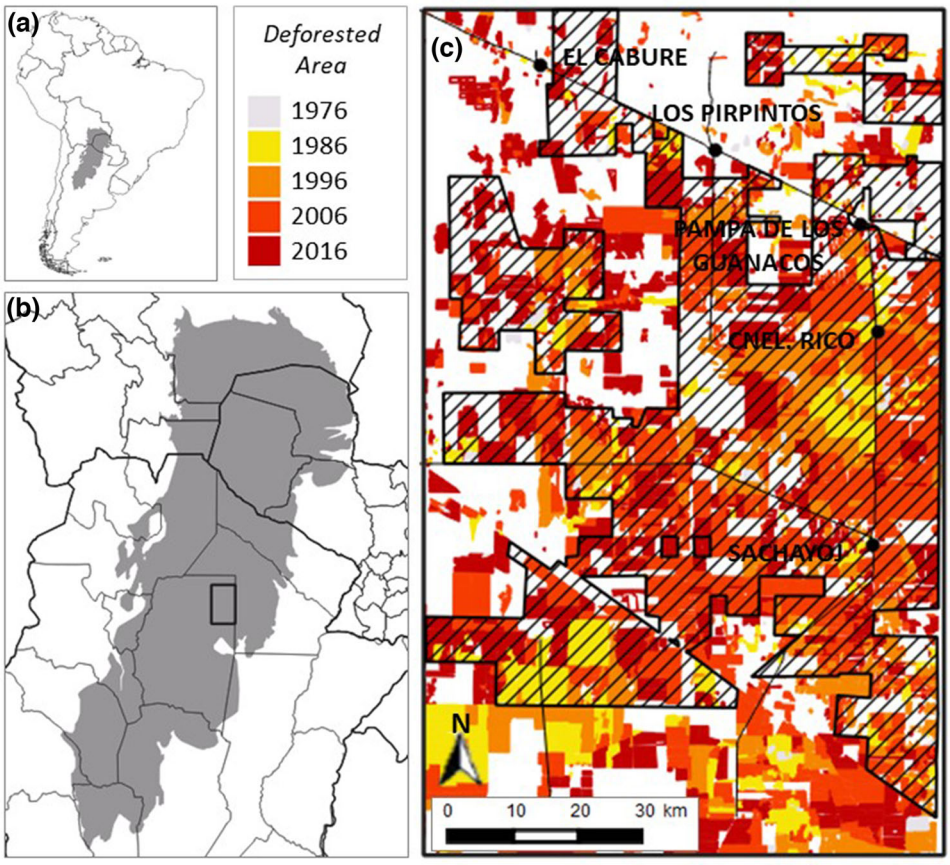

FIGURE 1 Location of (a) the Gran Chaco ecoregion in South America, (b) the northeast of Santiago del Estero in the South American Gran Chaco, and (c) the study area (black rectangle in b) in the northeast of Santiago del Estero. In (c), colors indicate the decade when land plots in the study area were deforested, and the shade indicates the distribution of the areas surveyed through key informant mapping

from 2003 to 2014 were above 3% (Camba-Sans et al., 2018), which is 3, 6, and 15 times higher than national, continental and global averages (1.1%, 0.5%, and 0.2%, respectively). Our findings have implications for the adaptive design of the Forest Law, a national legislation that has been in force since 2009 for the conservation and sustainable management of Chaco forests.

2 | METHODS

2.1 | Study area

The study area covers 690,000 hectares and is located in the northeast of Santiago del Estero province, at the center of the South American Chaco (Figure 1). It is part of the world's largest continuous tract of subtropical and tropical dry forests (Olson et al., 2001), and it has been one of the most active commodity production frontiers of the region (le Polain de Waroux et al., 2017). Despite its uniqueness, this region is highly threatened (Kuemmerle et al., 2017) and understudied (Hoekstra et al., 2005). Chaco seasonally dry forests are dominated by hardwood trees, mainly the intensively exploited quebrachos (*Schinopsis* spp.) and algarrobos (*Prosopis* spp.). Croplands and pastures have replaced 10.5 million ha of native ecosystems in the Argentine Dry Chaco by 2012 (Vallejos et al., 2015), and 1.4 million ha of dry forests in Santiago del Estero by 2014 (Camba Sans et al., 2018).

2.2 | Key informant mapping of land-tenure changes

Given the absence of complete and/or updated cadastral data in Argentina, we employed key-informant mapping to reconstruct the changes in land-tenure forms and land-user types that occurred in the last four decades (1976–2016) in the study area (full methodological description in SI). We selected seven key informants whose combined knowledge covered the study area and period. Each key informant was visited and interviewed by the authors in July 2018. During the interview, we presented informants with one printed map of the study area per period, each

containing a Landsat image of the end year (showing land covers for years 1976, 1986, 1996, 2006, and 2016) and main landmarks (roads, towns, and administrative boundaries). We asked informants to draw on a tracing paper overlaid to each map as many landholding polygons as they could locate and demarcate for the corresponding period. For each landholding identified, we asked informants to provide information of its attributes, with particular emphasis on (i) who possessed or owned the landholding (i.e., land-user type), (ii) which type of land title (if any) and associated bundle of rights the land-user hold (i.e., land tenure form), and (iii) when was it occupied/acquired and left/sold by the land-user.

We classified each landholding (polygon) in each period based on its land-tenure form and land-user type. Following Robinson et al. (2018), we identified two land-tenure forms in the study area, each defined by a particular bundle of rights: (i) private, when the land-user holds a property title and the full bundle of rights (access, withdrawal, management, exclusion, alienation and due process), and (ii) nonprivate, when the land-user did not hold a property title (could hold a possession title) nor the rights to refuse others access, sell or subdivide the landholding and adjudicate grievances or be compensated after expropriation. We classified land-user types based on the place of origin (i.e., local: from within the study area, extra-local: from other provinces or countries) of the person who possessed or owned the landholding, as this attribute is highly associated with his or her capital assets in terms of knowledge, education, social relations and financial capital (Mastrangelo et al., 2019). We obtained complete information on 122 landholdings and reconstructed their land-tenure changes all along the study period. After combining the two classification attributes, we classified each of the 122 landholdings in each decade into one of four possible agent classes: (i) extra-local private (ELP), (ii) extra-local nonprivate (ELNP), (iii) local private (LP), and (iv) local nonprivate (LNP). ELP and LNP classes together contained more than 70% of classified landholdings in every period (Table S1). Altogether, classified landholdings covered 419,337 hectares (61% of the study area). Unclassified landholdings were not associated with a particular factor nor clustered in space (Figure 1).

2.3 | Geospatial and data processing

To quantify and map forest cover changes for each decade, we used a geospatial database built to monitor deforestation in the Argentine Dry Chaco (available at https://www.monitoreodesmonte.com.ar). This database was built by manually digitalizing polygons of deforested plots from 1972 to the present, using Landsat imagery (see procedure in Vallejos et al., 2015). We accumulated deforested area within each period of analysis (until 1976, 1977–1986, 1987–1996, 1997–2006, 2007–2016) and obtained five spatial vector layers. In parallel, we digitalized analog maps from key-informant mapping, and obtained one spatial vector layer containing polygons of classified landholdings for each period of analysis. Then, we intersected spatial vector layers containing polygons of classified landholdings with those containing polygons of deforested plots for each period of analysis in QGis. Finally, we overlaid a grid containing 69 square cells of 10 km side onto intersected layers, and used grid cells as units of analysis in regression models (Figure 2).

2.4 | Statistical analyses

We employed contingency tables and *G* tests to test the association between each combination of land-tenure form and land-user type (i.e., agent classes) in each period (Crawley, 2006). We found significant association only for the most prevalent agent classes ELP and NLP, and applied regression analyses on these two agent classes. First, we compared the area under tenure, the deforested area, the proportion of area in an agent class that was deforested and the deforestation rate among the four agent classes using Welch t tests (Crawley, 2006; Sokal & Rohlf, 2012). Second, we employed linear regression models to test the association between the area under tenure and the area deforested within the area under tenure for ELP and NLP classes in each period (Quinn & Keough, 2002). We fitted regression models for each class and period through generalized minimum squares considering the area under tenure as a covariable of residual variance (Zuur et al., 2009).

3 | RESULTS

Mean landholding size in the study area ranged between 2112 and 3644 ha across decades, with that of ELP agents (5175 ha) doubling that of LNP agents (2604 ha) across the study period. The proportion of private land observed in the study area (77% in 2007–2016) is slightly higher than that reported for the whole province by the national census (62% in 2018). This is because the study area has better conditions for timber extraction and agricultural production, and showed an earlier formation of large properties, compared to the whole province (Camba-Sans et al., 2018). Changes in landholding size were characterized by a simultaneous subdivision of large properties and agglomeration of small landholdings. Three quarters of the area deforested across decades occurred in landholdings that were previously privatized (range 68%−79%).

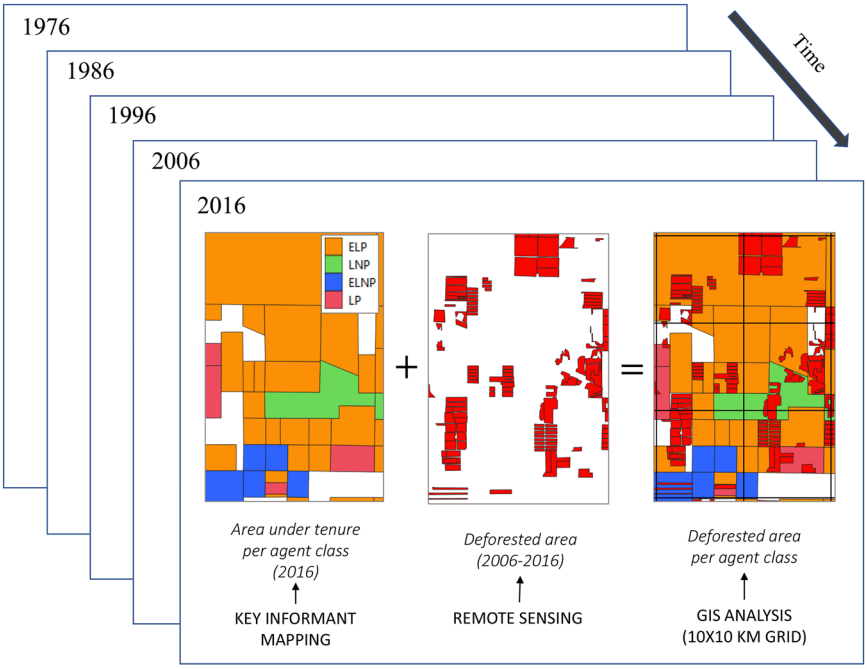

FIGURE 2 Methodological steps to test the spatial and temporal association between the area under tenure and area deforested by each agent class from 1976 to 2016 in the Northeast of Santiago del Estero. ELP: extra-local private, ELNP: extra-local nonprivate, LP: local private, LNP: local nonprivate

There was a significant association between land-tenure forms and land-user types ($X^2 = 157.9$, $p < .001$). Private land-tenure was associated with extra-local land-users, while nonprivate land-tenure was associated with local land-users. The observed frequency of extra-local private (ELP) agents was significantly lower than expected (under the independence hypothesis) at the beginning of the study period and significantly higher than expected in the last two decades (Figure 3a). Conversely, the observed frequency of local nonprivate (LNP) agents was significantly higher than expected (under the independence hypothesis) before 1976 and significantly lower than expected in 1997–2006 and 2007–2016 (Figure 3b).

Agent classes showed clear temporal patterns of change in area under tenure, deforested area, proportion of area in an agent class that was deforested and deforestation rate (Figures 4a–d). Before 1976, the area under tenure by LNP agents was 57% higher than that by ELP agents, but the deforested area was not different between agent classes. During the 1977–1986 decade, the area under tenure by LNP agents dropped below that of ELP agents, and the area deforested by ELP agents started to increase. In the following two decades, the area under tenure by ELP agents increased by 59 % while that by NLP and LP agents decreased by 47% and 45%, to the extent that ELP agents controlled an area more than 6 times larger than NLP and LP agents by 1997–2006 ($p < .01$). This was accompanied by a 670% increase in the deforestation rate and a 508% increase in the area deforested by ELP agents, which peaked at 67,210 hectares during 1997–2006 in coincidence with the arrival of genetically modified soybeans, compared to 3014 hectares deforested by NLP agents during

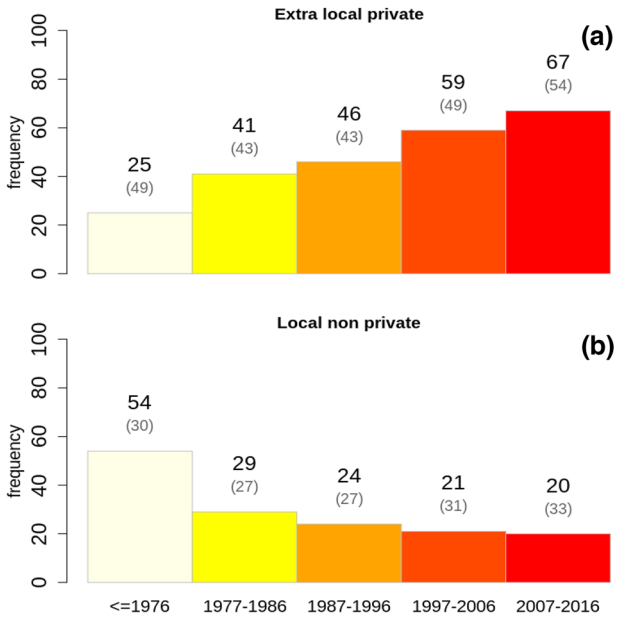

FIGURE 3 Frequencies of extra-local private (a) and local nonprivate (b) agents in each decade from 1976 to 2016. Numbers in bold are observed frequencies and numbers in parenthesis are expected frequencies under the independence hypothesis

that decade ($p < .01$). As a result, the proportion of area under tenure of ELP agents that was deforested increased from 0.1 during 1977–1986 to 0.3 during 1997–2006, when it was around 3 times larger than that of NLP and LP agents ($p < .01$). The proportion of area under tenure of ELNP agents that was deforested peaked at 0.4 in the 1997–2006 decade, when extra-local land-users rushed to deforest even not-yet-privatized lands in anticipation of the

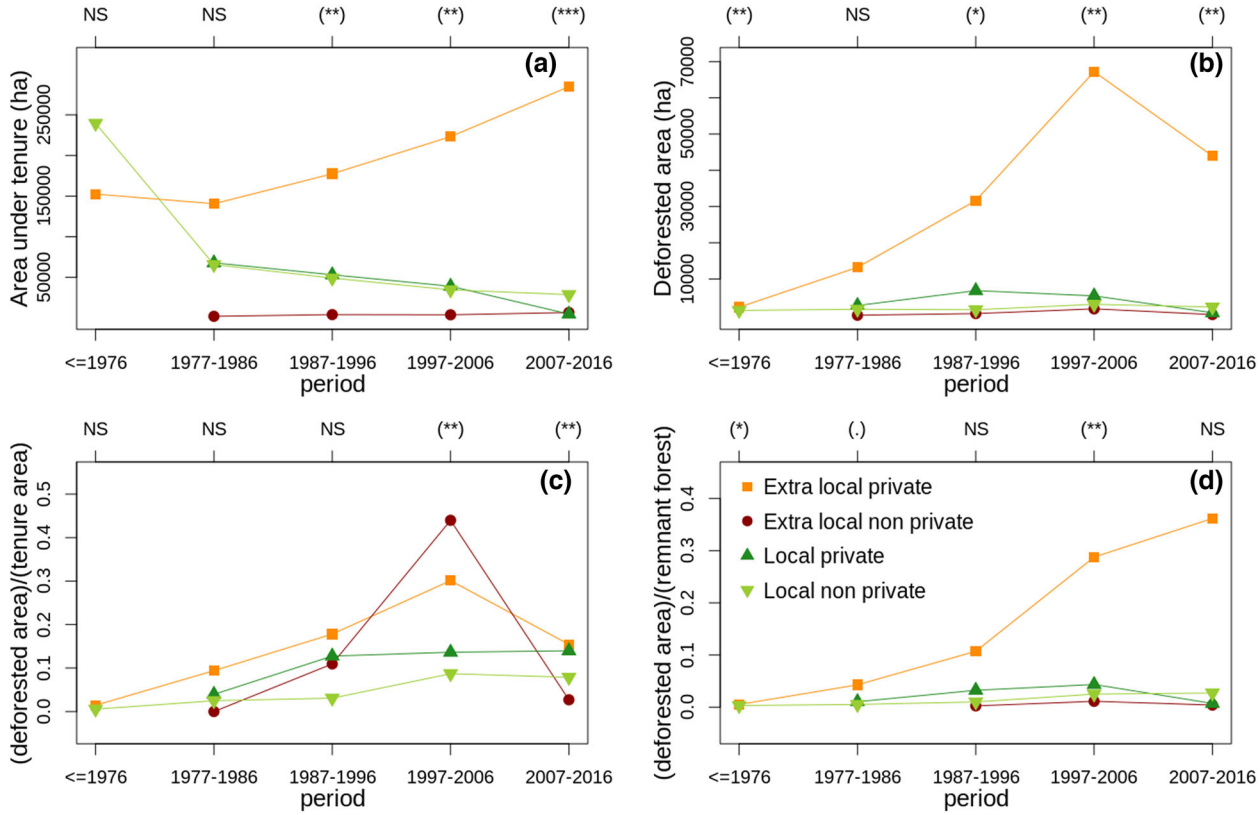

FIGURE 4 Changes in area under tenure (a), area deforested (b) proportion of area in an agent class that was deforested (c) and deforestation rate (d) for each of the four agent classes in the four decades from 1976 to 2016. $p < .1$, $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$

forthcoming Forest Law (Volante & Seghezzo, 2018). During the 2007–2016 decade, the area under tenure by ELP agents increased another 27% until reaching 284,612 has, but the area deforested by this agent class was 35 % lower than that in the previous decade, in coincidence with the implementation of the Forest Law.

The association between the area under tenure and the area deforested by ELP agents was positive and significant ($p > .001$) in each of the four decades from 1976 to 2016 (Figures 5a–e). In this period, the variation in the area under tenure by ELP agents explained between 25% and 45% of the variation in deforested area by ELP agents, indicating a strong temporal coupling between the area under tenure and the deforested area by this agent class across the four decades of analysis. The sensitivity of the deforested area to the variation in the area under tenure for ELP agents was higher in the 1997–2006 decade, when an increase in one hectare in land tenure was associated with an increase in 0.3 hectares in deforested area (Figure 5d).

In contrast, the association between the area under tenure and the area deforested by LNP agents was positive and significant only before 1976 and the 1977–1986 and 2007–2016 decades (Figures 5f–j). The variation in the area under tenure by LNP agents explained 38% of the variation in deforested area by LNP agents in the first decade of analysis, while it explained only 13% in the last decade of analysis. The sensitivity of the deforested area to the variation in the area under tenure for LNP agents was similar for the 1997–2006 and 2007–2016 decades, when an increase in one hectare in area under tenure was associated with an increase in 0.08 hectares in deforested area (Figures 5i–j). This sensitivity is 4 times lower than that of ELP agents for the same period.

4 | DISCUSSION

Forest conservation in commodity production frontiers requires reforming the incentives that motivate agents to deforest. Given the dynamics underlying forest loss in these regions, this requires a smart mix of governance instruments, including stricter enforcement of existing land-use plans (Volante & Seghezzo, 2018), supply-chain initiatives and payments for ecosystem services (Lambin et al., 2018), and forest management by local people (Marinaro et al., 2015). The effectiveness of all these instruments is strongly influenced by interactions between characteristics of the land-use decision-maker and the bundle of rights she holds over the land (Robinson et al., 2018). Our study is the first to quantify and map such

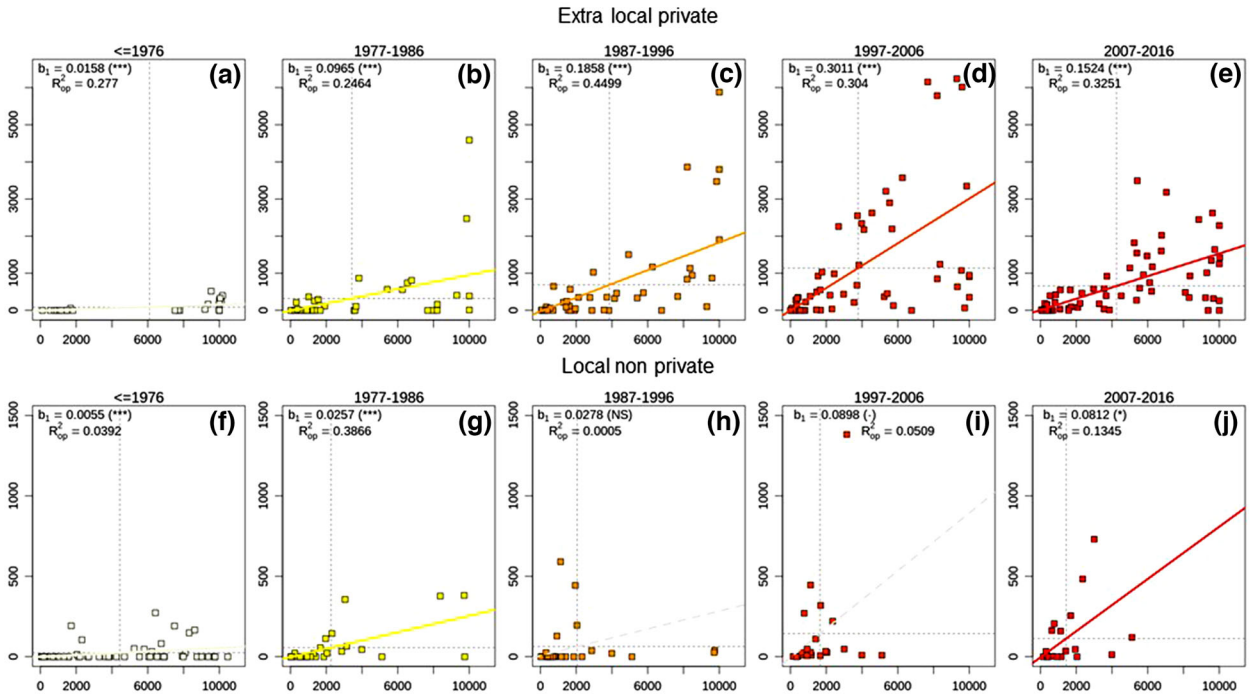

FIGURE 5 Output of regression models testing the association between area under tenure and deforested area by extra-local private agents (a–e) and by local nonprivate agents (f–j) before 1976 (white dots), during 1977–1986 (yellow dots), during 1987–1996 (orange dots), during 1997–2006 (light red dots) and during 2007–2016 (dark red dots). $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$

interactions over a long time period within a global deforestation hotspot.

Our analysis shows some methodological innovations. Key-informant mapping proved useful for uncovering "who owns the land," a piece of information critical for policy-relevant knowledge but often under secrecy (McSweeney & Coomes, 2020). Our decadal analysis goes beyond snapshot studies as it allows looking at the temporal coupling between land-tenure and forest cover changes. Our study has also some limitations and caveats. We assessed the influence of land-tenure form but not of land-tenure security, as this is a subjective measure difficult to obtain for large geographical areas and past periods (Robinson et al., 2014). Even recalling objective measures such as land-tenure form poses challenges to key informants, and given the low number of informants, this information should be considered with caution. The choice of a 10 km^2 grid cell as unit of analysis was determined in relation to the mean landholding size, but can also be a source of statistical bias. Finally, recent evidence (Marinaro et al., 2020) and our analysis indicate that land privatization very often precedes deforestation and not the other way around; however, more complex forms of endogeneity cannot be fully ruled out.

We found a rapid change in the dominance of agents from 1987 to 2016 in a typical commodity production frontier of the Argentine Dry Chaco (Figure 4a). This is in line with a general trend of outmigration of local land-users and immigration of extra-local ones from 1988 to 2002 (Paolasso et al., 2012a). These new land-users have been associated with increases in landholding size and in the area cultivated with annual crops, mainly soybeans (Cáceres, 2015; Krapovickas, 2010). Soybean cultivation was strongly coupled to deforestation during the 1972—1997 and 2002—2011 periods, and transiently decoupled from 1997 to 2002 due to domestic economic recession and low international prices (Gasparri et al., 2013). Deforestation rates decreased during the 2007–2016 period in synchrony with the Forest Law, although this trend has been mainly attributed to declining soybean international prices (Volante & Seghezzo, 2018). These pieces of evidence combined highlight the links among macroscale economic drivers (i.e., international commodity prices), mesoscale triggering factors (i.e., land-privatization by extra-local land-users) and local environmental impacts (i.e., deforestation for soybean expansion).

Our findings support the notion that the complex relation between land-tenure forms and forest cover is mediated by the social and economic characteristics of land-users (Busch & Ferreti-Gallon, 2017). Where market forces and State policies favor forest conversion to agriculture, a strong spatial and temporal coupling between land privatization and deforestation as that found here in the Argentine Dry Chaco is likely observed. Even where land titling

results from State action, landholders with property titles may deforest more as long as market forces promote conversion to agriculture, as observed in the Brazilian Amazon (Wren-Lewis et al., 2020). This outcome likely arises where land-use options requiring forest clearing (e.g., soybean cultivation) are more economically profitable than those compatible with forest conservation (e.g., sustainable forestry, ecotourism) (Robinson et al., 2014). Where this economic incentive aligns with a tendency of land-users to develop nonforest land-use systems, such likelihood is even higher. Extra-local land-users responsible for most deforestation in our study area (and the dry Chaco forests as a whole) prefer to cultivate soybeans and raise cattle on cleared lands due to higher profitability, and also because these are the land-use systems they are used to deploy in the humid Pampas grasslands where they come from (Caceres, 2015).

The history of changes in the agents of deforestation reported here differs from what occurred in South Asian countries where land-tenure forms changed but land-user types remained the same as a result of large State-led land formalization programs, which converted insecure land possessors into private land-owners (Rudel & Hernandez, 2017). In contrast, it resembles what occurred in Central Africa and other Latin American countries, where international market demand and neoliberal policies stimulated the penetration of foreign and extra-local investments into remote rural areas inhabited by local land-users with insecure land tenure (German et al., 2014). Both State-led and market-led land-tenure changes have been associated with large-scale deforestation and severe environmental impacts, while the latter also with increased socioeconomic inequality (Rudel & Hernandez, 2017). Observed changes in the dominance of agents in the Chaco region have been associated with processes of land dispossession of local land-users by arriving farmers and investors (Caceres, 2015; Mastrangelo & Aguiar, 2019; Vallejos et al., 2020), creating paradoxical landscapes with high levels of poverty and high export commodity production (Paolasso et al., 2012b).

Our findings suggest governance options for improving local development while maintaining forest cover in the dry Chaco region. If extra-local land-users privatize lands to secure the investments that yield the comparatively higher economic returns, adding value to economic activities compatible with forest maintenance can decouple land privatization and deforestation (Aguiar et al., 2018). This can be achieved through public policies for the promotion of sustainable forestry, nontimber forest production and ecotourism. Also, by improving the implementation of a program within the Forest Law that provides economic compensations to land-users that maintain forest cover in their landholdings (Alcañiz & Gutierrez, 2020). A major improvement would be allowing LNP agents to access these compensations, as forest cover in more than 90% of the lands they hold has been maintained in each of the last four decades (Figure 4b). Moreover, LP agents have maintained forest cover in a proportion similar to LNP agents (Figure 4c), thus granting the full bundle of land rights to LNP agents has potential to advance local development without conservation costs, for instance, by allowing them accessing credit to invest in forest-friendly economic activities (Mastrangelo et al., 2019).

ACKNOWLEDGMENTS

This study was funded by Agencia Nacional de Promoción Científica y Tecnológica and Ministerio de Ambiente y Desarrollo Sustentable (PICTO 2014-0046) and the 50th Anniversary Research Fund of the Landscape Research Group on “Landscape Justice.” We thank key informants for their contributions to field data collection, and three anonymous reviewers for their helpful comments.

AUTHOR CONTRIBUTIONS

MEM designed the study; MF, MV, and MEM collected data; MF, MV, and MT analyzed data; and all coauthors contributed to manuscript writing.

ETHICS

Informed consent was obtained from all individual participants involved in the study.

DATA ACCESSIBILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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SUPPORTING INFORMATION

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How to cite this article: Faingerch M, Vallejos M, Texeira M, Mastrangelo ME. Land privatization and deforestation in a commodity production frontier. *Conservation Letters*. 2021;e12794. https://doi.org/10.1111/conl.12794