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The potential impact of economic policies on future land-use conversions in Argentina

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ABSTRACT

Agricultural expansion and intensification drive the conversion of natural areas worldwide. Scenarios are powerful tools to explore possible future changes in agricultural land use, how these may affect the environment, and how policies may influence land-use patterns. Focusing on Argentina's prime agricultural areas, the Pampas, Espinal and Chaco, we developed spatially-explicit future land-use scenarios from 2010 to 2030, considering both agricultural expansion (i.e., conversions from woodland to either grazing land or cropland) and agricultural intensification (i.e., conversions from grazing land to cropland). Our simulations were based on an econometric model of net returns, which assumes economically rational land-use actors. Using this model, we assessed the rates and spatial patterns of future land-use change under current land zoning in our study region, and contrasted this with a forecast of future land use based on land-conversion rates from 2000–2010. We systematically tested the impact of economic policies (e.g., taxes or subsidies), infrastructure improvement (e.g., road paving), and technological innovation (i.e., yield increases) on the spatial patterns of land-use conversions. Our model suggests future land-use change will mainly happen along intensification pathways, with deforestation slowing down, if land-use actors would be profit-maximizing. This general pattern did not change even for policy interventions that impacted profits from agriculture in major ways, cautioning against overestimating the leverage that economic policies provide for halting deforestation. Improving the region's road network would create a strong incentive to expand cropland further into remaining woodlands and over grazing lands. However, low agricultural profits and higher yields could curb deforestation in marginal areas to some extent. We also highlight that priority areas for conservation are particularly likely to experience high land-use pressure in the future. Given the lower-than-expected power of economic policies to alter deforestation patterns in our models, zoning, if properly enforced, appears to be a more straightforward tool for avoiding unwanted environmental impacts in the Chaco.

1. Introduction

Agricultural expansion and intensification drive the loss of natural vegetation worldwide, leading to the degradation of biodiversity and ecosystem services (Leblois et al., 2017; Maxwell et al., 2016). This is especially the case for the world's tropical and subtropical dry forests, where much of the remaining non-cultivated fertile land is found (Lambin et al., 2013; Laurance et al., 2014; Ramankutty et al., 2002). With ongoing population growth and even greater increasing consumption, the demand for agricultural products is expected to rise

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dramatically in the 21st century (Foley et al., 2011; Tilman et al., 2011). This will translate into growing pressure to intensify existing agriculture areas and to expand agriculture into natural ecosystems. Identifying policies that effectively steer agricultural land-use change and assessing their relative impact on agricultural expansion versus intensification pathways, is therefore critical (Angelsen, 2010; Meyfroidt et al., 2014).

This requires understanding the underlying causes behind agricultural land-use changes (e.g., changes in population, diets, market prices) and how they play out in given local conditions (e.g., soils, climate, accessibility, policies) (Geist and Lambin, 2002; Meyfroidt, 2015). South America harbors some of the world's key agricultural regions, where agricultural land-use change is strongly influenced by global agricultural markets (Byerlee et al., 2014; Gasparri and le Polain de Waroux, 2015). This has resulted in widespread deforestation for cattle ranching and soybean cultivation (Baumann et al., 2016a; Gasparri et al., 2013; Leblois et al., 2017). Yet, deforestation rates vary starkly from region to region, depending on the environmental characteristics and the national and subnational policy framework (Assunção et al., 2013; Macedo et al., 2012; Nolte et al., 2017). For example, whereas deforestation rates in the Amazon or the Paraguayan Atlantic Forest have decreased recently (Nepstad et al., 2014; WWF, 2006), in part due to forest protection policies (Baumann et al., 2017; Macedo et al., 2012), agricultural expansion in the neighboring Cerrado and Chaco ecoregions continues unabated (Baumann et al., 2016a; Spera et al., 2016). Likewise, agriculture in some regions, such as in the Pampas or the Atlantic Forest, has intensified from cattle ranching to soybean production (Bert et al., 2011; Viglizzo et al., 2011; WWF, 2015). In order to efficiently manage agricultural land-use change, it is therefore crucial to understand its underlying causes and how broad-scale policies, that governments or land-use planning agencies can implement, may impact future land-use patterns.

Scenario analysis is a powerful tool to explore how future land use might change in response to alternative policies (Gavier-Pizarro et al., 2014; Peterson et al., 2003; Piquer-Rodríguez et al., 2015; Polasky et al., 2011). If landowners seek to maximize profits from land, which is typically the case in agricultural frontiers, key factors influencing their decisions are those directly affecting agricultural profitability (Barbier, 2012; Bockstael, 1996; Le Polain de Waroux et al., 2018). Spatial economic models of net returns explicitly model the impact of changes in land profitability (i.e., net returns) on land-use change patterns, while accounting for regional variations in agricultural suitability (Butsic et al., 2011; Piquer-Rodríguez et al., 2018; Radeloff et al., 2012). Once parameterized, such models allow for insights into the impact of changes in underlying drivers of land-use change, to explore alternative future scenarios, and to test for the possible effects of specific policies on land-use change (Butsic et al., 2010; Lewis and Plantinga, 2007; Radeloff et al., 2012). This is a major advantage compared to models that project future land-use change based on correlations between past land-use change and its spatial determinants, while typically disregarding the mechanisms driving land-use change (Plantinga and Lewis, 2014). Yet, to our knowledge, only two models of net returns have been parameterized for agricultural regions in South America (Arima, 2016; Seo, 2009), and only one, from our own previous work, has used spatial data on agricultural costs and returns to assess profits directly (Piquer-Rodríguez et al., 2018).

Within South America, Argentina is a hotspot of agricultural land-use change, both in terms of agricultural intensification and expansion (Viglizzo et al., 2011). Widespread conversion of grazing land to cropland has occurred in the Pampas and Chaco ecoregions, mainly for the production of soybean, corn, and wheat. At the same time, agricultural expansion into the dry forests of the Chaco ecoregion, both for expanding cropland (i.e., soybean, wheat, maize, and cotton) and cattle ranching, is widespread (Baumann et al., 2016a; Gasparri et al., 2015; Grau et al., 2015; Volante et al., 2016). These trends are likely to continue in the future (Laurance et al., 2014; Ramankutty et al., 2002; Schmitz et al., 2014), which is concerning given the stark environmental trade-offs these land-use changes had in the past (Baldi et al., 2006; Baumann et al., 2016a; Macchi et al., 2013; Mastrangelo and Gavin, 2014; Torres et al., 2014).

Continued development of its agricultural sector has turned Argentina into a major global producer and exporter of soy and beef since the 1990s (Leguizamón, 2016; Urcola et al., 2015). For example, soybean production increased from hundreds of tons in the early 1970s to approximately 50 million tons in 2010 (Leguizamón, 2014). Among the total agricultural produce exported, soy and derivatives account for the highest export shares in Argentina, and the country is an important oil and biodiesel producer globally (CIARA, 2017). Export mainly comes from large and medium-sized agribusinesses (Gasparri and le Polain de Waroux, 2015; Le Polain de Waroux et al., 2018; le Polain de Waroux et al., 2016) and agricultural trade is an income source and a stabilizing factor for the Argentine economy (Meller, 1994). Due to the crucial role of the agricultural sector for Argentina's economy, governmental policy interventions at the national level (e.g., the creation or lifting of export taxes (Gasparri and Grau, 2009)) and provincial level (e.g., infrastructure improvement (e.g., Plan Belgrano, Decree 12/2015)) are frequent.

Understanding how national or provincial-level land-use policies influence spatial patterns of agricultural land-use change in Argentina is therefore important. Land-use policies could target agricultural profits directly, for example via export taxes or through subsidies, as is currently the case (e.g., *retenciones*). This affects medium to large-scale commodity producers because they are integrated in international markets and profit mainly from the production of export oriented goods and has a direct impact on deforestation rates (Gasparri et al., 2013; le Polain de Waroux et al., 2016). More indirect policy interventions include agricultural production targets or caps, such as the Strategic Food and Agricultural Plan (MAGyP, 2011) or the 'Hilton Quota' on beef exports to the European Union (Decree 906/2009 and 1231/2015). Moreover, policies can affect the agricultural sector via infrastructure development (e.g., Infrastructure Investment Plan to 2025 (Bortolín, 2015), Executive Network Framework to 2024 -E.Di.Vi.Ar or Plan Belgrano) via lowering transportation costs, thereby raising land rents (Choumert and Phélinas, 2015). This impacts agricultural producers strongly, as transportation costs are a limitation especially for small-to-medium scale producers (Le Polain de Waroux et al., 2018). As a result, land-use conversions often expands from already converted areas, where infrastructure, logistics, knowledge, labor, and technology are in place, creating typical agricultural frontiers where natural resources are not as important as agglomeration economies (Garrett et al., 2013; Gasparri et al., 2015; Piquer-Rodríguez et al., 2018; Richards, 2018; Volante et al., 2016). In contrast, however, leap-frogging land-use conversions into marginal regions does occur, often by risk-taking actors in expectation of extraordinary profits (Le Polain de Waroux et al., 2018). How policies targeting profits directly (e.g., via taxes) or indirectly (e.g., via improving infrastructure and thus lowering transportation costs) may influence rates and spatial patterns of future agricultural land-use change in Argentina, however, remains unclear.

Existing work on future agricultural land-use change in Argentina typically explores alternative narratives of potential future agricultural trends (Adamoli et al., 2011; Patrouilleau et al., 2007; Patrouilleau et al., 2012). These studies generally suggest that land ownership is increasingly concentrated in the hands of a few producers (Baumann et al., 2016b; Bert et al., 2011; Corral et al., 2008), and highlight the potential of intensification for increasing agricultural productivity (Canosa et al., 2013). Because these studies are not spatial, assessing the environmental impact of future land-use, and how particular policies would affect these impacts, is challenging. Conversely, studies that considered the spatial patterns of future land use were all based on correlative models that disregard underlying causes of agricultural conversions, such as land profits (Gasparri et al., 2015; Volante et al., 2016).

Our goal here was to explore potential future pathways of agriculture in Argentina's Pampas, Espinal and Chaco regions. We built on an existing spatial economic model of net returns, that included actual agricultural profit and land-use/cover conversion data, parameterized for the period 2000–2010 (Piquer-Rodríguez et al., 2018). We used this model to explore potential agricultural expansion and intensification until the year 2030, and to test how different economic policies, infrastructure development, and technological innovations, would impact these land-use changes. Importantly, our model assumes profit-maximizing land-use actors. Given that past land-use changes may also be driven by non-economic factors (e.g., land zonation or cultural ties to the land (Piquer-Rodríguez et al., 2018, 2015)), we also explored the impact of the same policies on scenarios where we forecast land use based on historical conversion rates. This allowed us, for the first time to our knowledge, to assess the potential future effects of a wide range of policies on land-use change patterns in Argentina, while isolating the individual effect of each specific policy. Finally, we compare our future agricultural scenarios with regions of conservation priority to detect possible conflicts. Specifically, we asked three research questions:

1 What are the likely rates and locations of agricultural expansion and intensification in Argentina until 2030, assuming profit-maximizing land users?
2 Where would land-use changes occur when forecasting historical (2000–2010) agricultural land-use change rates until 2030?
3 How would different economic policy interventions (e.g., taxes, subsidies, investment into infrastructure) affect land-use change rates and patterns until 2030?

2. Materials and methods

2.1. Study area

Our study area covered the main agricultural ecoregions of Argentina: the Pampas, the Espinal and the Chaco regions (~1.3 million km^2, Fig. S1), which are generally flat, except for some hilly areas in the west. The climate transitions from temperate (Pampas) to subtropical (Chaco), with lower rainfall in the West (800 mm) than in the East (1100 mm), and the driest parts in the central and southern Chaco (300–400 mm) (Herrera et al., 2014; Morello et al., 2012). Soils in the Chaco vary from well-suited for agriculture in the north (i.e. rich in minerals and fine texture) to marginal in the southwest (i.e., sandy soils, low organic matter content (Burkart et al., 1999). The soils in the Pampas are generally very rich (Herrera et al., 2014).

Natural vegetation in the Pampas is characterized by grasslands, mainly composed of *Stipa sp*., *Briza sp*., *Bromus sp*., and *Poa* sp. (Cabrera, 1971). In the Chaco, trees of the genera *Schinopsis* and *Aspidosperma* ("quebrachos") are characteristic, along with Ziziphus ("mistol"), *Prosopis* ("algarrobo"), *Acacia* shrubs and *Cactaceae* in the dry Chaco and *Prosopis* ("algarrobo"), grasslands with *Stipa* sp. and *Trithrinax* sp. (palm savannas*)* in the wet Chaco (Prado, 1993). The Espinal constitutes a transition zone between the Pampas and the Chaco and is characterized by shrublands (mainly *Prosopis caldenia* ("calden"), *Caprris atamisquea* ("atamisque") and *Psila spartoides* ("pichana")) and grasslands, as well as *Prosopis* sp*., Acacia* sp., and *Aspidosperma* sp. trees (Burkart et al., 1999). Biodiversity in all three regions is high, though protected area networks are generally sparse, covering only 1,9% of the total area with many areas of conservation priority outside these reserves (Bilenca and Miñarro, 2002; TNC, 2005). For our study, we split the Espinal ecoregion and merged it to the Pampas or to the Chaco ecoregions based on ecological similarity (Fig. S1).

The Pampas has a longer land-use history than the Chaco, as cattle ranching in these productive grasslands has been practiced for centuries. With the introduction of soybeans in the 1970's, many pastures in the Pampas were converted into soybean fields and ranching was displaced first into the Espinal and then into the more marginal Chaco (González-Roglich et al., 2015; Pengue, 2014). By the end of the 1990s, increasing soybean prices and new genetically modified soybean varieties spurred soybean expansion into the Espinal and Chaco at the cost of native woodlands (Leguizamón, 2016). Between 2000 and 2010, cropland in our study region expanded steadily by 152,000 km^2 (133,200 km^2 from grazing land and 18,300 km^2 from woodland), with an additional 27,000 km^2 of grazing land expansion into woodlands. This translated into about 14% of the Argentine Chaco woodlands being converted to agriculture during the 2000s (Baumann et al., 2016a).

2.2. Data used for model building

To build our spatial model of net returns (hereafter: Net Returns Model – NRM), we developed a homogenized map of past land-use conversions in 2000 and 2010, pertaining to three types of conversions: (1) grazing land to cropland (here defined as agricultural intensification), (2) woodland to cropland, and (3) woodland to grazing land (i.e., both the latter land-use changes refer to deforestation by agricultural expansion). These land conversions formed our dependent variables (Table S1).

As predictor variables for the years 2000 and 2010, we compiled an extensive dataset of crop and cattle yields, farm-gate producer prices, and direct costs in order to generate our cropping- and grazing-related profit variables. While originally surveyed at the farm level, these data are available only in aggregate form and are captured at different scales (Piquer-Rodríguez et al., 2018). Yield data was available at the district level (i.e., *departamentos*), farm-gate prices were available at the country scale and costs were available at the eco-region scale. We downscaled these data to the pixel level (i.e., 1 × 1 km). See Supplementary Material B for further detail. We also included a wide range of control variables at 1-km resolution (i.e., pixel size), including climate (e.g., aridity index), accessibility (e.g., travel cost to provincial capitals), topographic (e.g., slope), edaphic (e.g., soil productivity), and neighborhood variables that accounted for the spatial clustering of agriculture in the region (Volante et al., 2016) (Table S1). We expected spatial clustering of agricultural expansion to be based on a number of economic foundations. First, transportation cost and the cost of clearing land are likely lowest adjacent to already cleared forest (as machines and labour will not have to move far). Second, network effects may cause nearby landowners to share knowledge about profits (Le Polain de Waroux et al., 2018)or how to successfully farm, triggering other landowners to act in similar ways (and thus to clear more land for agriculture) (Richards, 2018). Third, as farms expand, we expect agglomeration effects and increasing returns to scale (Krugman, 1991), resulting in expanding operations as per-unit cost decreases (Garrett et al., 2013). For all of these reasons we expected land near already converted land to be deforested at high rates and thus we included a set of neighborhood variables (Table S1).

Although other socio-economic variables such as cultural ties to the land, economies of scale, land tenure, speculation, or land markets may influence land-use conversions in the region (Piquer-Rodríguez et al., 2018), we were not able to include those for lack of data. Note that we accounted for such potentially missing variables by comparing land-use simulations with and without constraining land-use change to historic (2000–2010) land-use change rates.

We used a multinomial logit model for jointly modelling conversions from woodland to either grazing land or cropland, and a logit model for modelling conversions from grazing land to cropland at the 1-km pixel scale. We validated our models by predicting 2010 land-use patterns based on year-2000 land use. Both models had a prediction accuracy above 80%, suggesting very robust model performance (see Supplementary Material B and Piquer-Rodríguez et al. (2018) for further detail).

2.3. Baseline scenarios of future agricultural land use

To simulate future agricultural land use, we used the NRM outputs of the likelihood of future land-use conversions for each pixel (Lawler et al., 2014; Radeloff et al., 2012). Generally, for all our simulations (described below), we updated neighborhood variables once in 2020, assuming that environmental conditions, road construction, and profits were static over the time period modelled (OCDE/FAO, 2014). We allowed agricultural land-use changes in accordance with the current national zoning policy (i.e., the Argentine National Forest Law #26331) that restricts conversions from grazing land or woodland to cropland (Supplementary Material, Fig. S1). Woodland to cropland conversions were only allowed in 'green' zones, woodland to grazing land conversions were allowed in 'green' and 'yellow' zones, assuming that conversions in 'yellow' areas follow the law and are done under a sustainable silvopastoral management plan (e.g., National Plan of Forest Management with integrated cattle ranching, -PNMBGI in Spanish, Exp.: 0008734/2015. Conv. N° 32/2015). We did not allow for land conversions in currently protected areas ('red' zones). Provincial forest laws can specify additional and more detailed land-use conversion rules at the cadastre plot level that, however, we did not take into account in our broad-scale ecoregion-wide analyses.

Exploratory scenario analyses is interesting to evaluate how much a system trajectory can be changed through policies (Gavier-Pizarro et al., 2014; Milburn, 2005; Peterson et al., 2003). We simulated four baseline scenarios (Table 1). First, we simulated future agricultural land-use changes assuming that land users seek to maximize profits from land use, as assumed in our NRM (baseline scenario 1 – *BS1;* Table 1). For our second baseline scenario, we altered BS1 by assuming increasing crop yields (baseline scenario 2 – *BS2*) through continued technological innovation and/or improved management, as foreseen by the Strategic Food and Agricultural Plan (MAGyP, 2011). In our third baseline scenario, we assumed historical rates of land-use conversions (i.e., 2000–2010) and constant yields (baseline scenario 3 – *BS3*), thus partly accounting for factors not included in our NRM, such as traditional uses of the land, land speculation, land access or capital availability. Our fourth baseline scenario combined BS3 with the yield increases of baseline scenario BS2 (baseline scenario 4 – *BS4*). See Supplementary Material C1 for more detail on the four baseline scenarios.

To model our baseline scenarios *BS1* and *BS2*, we projected the NRM to the years 2020 and 2030 in order to derive land-use transition probabilities. A pixel was assumed to convert from one land-use/cover to another if the simulated probability of conversion was higher than a randomly drawn probability (Radeloff et al., 2012). To ensure model stability and to account for stochastic variability, we ran a Monte Carlo simulation repeating this process 1000 times, resulting in 1000 individual land-use simulations for each time step (2020 and 2030). The final land-use class was assigned using a majority rule. To assess the robustness of our simulations, we calculated the deviation of model fit measures (pseudo R^2, AIC) for each simulation (Akaike, 1973; Hu and Palta, 2006), as well as the prediction power by calculating the ratio of observed vs. predicted values from the confusion matrix (Pearce and Ferrier, 2000), see Supplementary Material B for more details.

Given that past land-use changes may also be driven by non-economic factors due to (1) land users in the region that may not focus on maximizing land profitability (e.g., indigenous communities or traditional uses of the land) (Le Polain de Waroux et al., 2018; Marinaro et al., 2017), (2) land zonation that may restrict uses (Piquer-Rodríguez et al., 2018, 2015) or (3) other socio-economic factors not captured in our model such as corruption, land-tenure regimes, or land markets (Garrett et al., 2013; Gasparri et al., 2015; le Polain de Waroux et al., 2016), we also explored the resulting land-use patterns from scenarios where we forecast land use based on historical conversion rates. For scenarios *BS3* and *BS4*, we simulated land-use patterns for 2020 and 2030 based on the conversion rates observed in 2000–2010 (i.e., assuming constant land-use change). Thus, we assumed 18,300 km^2 of woodland to cropland conversions in 2010–2020, and again in 2020–2030. Similarly, we assumed 27,400 km^2 of woodland to grazing land conversions and 133,200 km^2 of grazing land to cropland conversion for both 2010–2020 and 2020–2030 (Fig. 1). To implement these conversions, we chose the pixels with the highest transition probabilities based on the NRM simulations until the targeted area for a specific land-use conversion was reached.

Table 1
The four baseline scenarios.

Baseline Scenario	*Scenario description*
BS1	Land-use change rates from the NRM (profit maximization) with stable crop yields.
BS2	BS1 with crop yield increases.
BS3	Land-use change rates as in the period 2000-2010 with stable yields.
BS4	BS3 with crop yield increases from BS2.

2.4. Economic policy interventions

For each of our four baselines scenarios, we evaluated the effect of four contrasting economic policy interventions (PI) on land-use conversions in our study region until 2030. These policy interventions were: PI-1 that decreased profits from cropping and ranching by 50%. This could happen by raising existing taxes or establishing new taxes. PI-2 increased profits from cropping and ranching by 50%. This could happen by lowering taxes, installing subsidies, or lowering export caps. PI-3 improved roads to the provincial capitals, with the goal of connecting these capitals with agricultural frontiers. PI-4 improved roads between main towns and major export hubs (including the capitals), with the goal of connecting these towns to export hubs (e.g., Buenos Aires and Santa Fe's harbors). See Supplementary Material C for more detail on these policy interventions.

Together, this resulted in a total of 20 scenarios (i.e., four baseline scenarios without policy interventions, plus four policy interventions per baseline scenario; Table 2 and Supplementary Material C). These scenarios are firmly grounded on developments foreseen for the agricultural sector (e.g., Strategic Food and Agricultural Plan (MAGyP, 2011) or regarding infrastructure development (e.g., Road Development Plan of the Federal Council Network of Argentina). Similarly, while some of the profit changes we simulated are strong, such changes have occurred in the past, for example stark changes in export taxes on commodities or production caps on meat (Res. MAGP N° 4/2017, published 03.02.2017, Disp. MAGP N° 6/2015, Fernández (2014), Passaniti (2011)). For more information see Supplementary Material C2.

Once we simulated future land-use maps for all of our 20 scenarios, we summarized the number of times each pixel experienced agricultural land-use conversion. To highlight where agricultural land-use change may conflict in the future with biodiversity conservation, we compared the map of conversion frequency to the priority areas highlighted in the "Conservation Portfolio of Priority Areas for Biodiversity" of the Chaco, developed by The Nature Conservancy (TNC, 2005). Likewise, we compared our conversion frequency map with the Valuable Pasture Areas (VPAs) of Argentina, which are areas of natural grasslands of high conservation value (Bilenca and Miñarro, 2002). Those TNC or VPA areas that were located within areas of high likelihood of experiencing agricultural conversions were classified as areas of conservation concern.

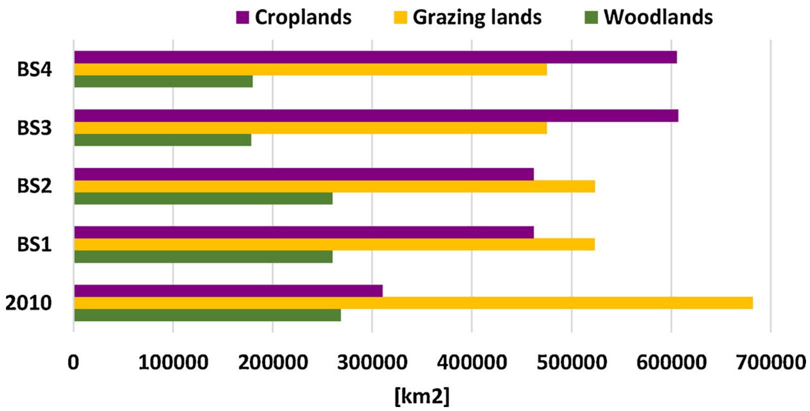

Fig. 1. Area (km^2) of land-use/cover simulated for each baseline scenario in 2030. Land use in 2010 is shown for references purposes.

Table 2
Description of our four economic policy interventions. Each of these was simulated for the four baseline scenarios in Table 1.

Policy interventions (PI)		*Description*
PI-1	Profit decrease 50%	Implementation of policies, such as export taxes or production caps, which decrease profits for cropping and ranching by 50%.
PI-2	Profit increase 50%	Implementation of policies, such as export taxes or production caps, which increase profits for cropping and ranching by 50%.
PI-3	Road improvement between capitals	Road improvement in the vicinity of provincial capitals.
PI-4	Road improvement around towns	Road improvement in the vicinity of major towns.

3. Results

3.1. Future land use in the four baseline scenarios

Simulating future land use assuming stable yields and profit-maximizing actors (*BS1*) showed marked agricultural land-use change between 2010 and 2030. For the first period (2010–2020), we observed a tendency towards agricultural intensification (i.e., grazing land to cropland conversions) whereas the second period (2020–2030) was characterized by both agricultural expansion (woodland to grazing land or cropland conversion) and intensification. Agricultural expansion was not widespread though (2200 km^2 in 2010–2020, and 5800 km^2 in 2020–2030, respectively), resulting in only a moderate (~3%) woodland loss compared to 2010, mainly located in Tucuman, Santiago del Estero and Salta; Fig. 1 and 2. Agricultural intensification (i.e., grazing land to cropland conversions) covered a staggering 67,500 km^2 in 2010–2020 and 79,600 km^2 in 2020–2030 (Fig. 1). Agricultural intensification occurred more clustered in the provinces of Chaco, Santiago del Estero and Entre Rios and more widespread in Cordoba, Santa Fe, La Pampa and Buenos Aires (Fig. 2). Overall, 96% of the new cropland in 2020–2030 came from agricultural intensification, and only 4% from agricultural expansion. Likewise, 54% of the total deforestation was due to cropland expansion and 46% was due to grazing land expansion.

Our second baseline scenario (*BS2*) was similar to the first (*BS1*) but assumed increasing yields. Agricultural expansion and intensification showed similar rates and spatial patterns as in baseline scenario 1 (*BS1*). Agricultural expansion in 2010–2030 was not very widespread, resulting in a similar overall woodland decrease than *BS1* (8000 km^2). A difference between the two scenarios was that agricultural intensification occurred more spatially concentrated in *BS2* when compared to the *BS1*.

Baseline scenarios 3 (*BS3*) and 4 (*BS4*) assumed future agricultural conversions at rates of 2000–2010 which resulted in higher area of land converted than in baseline scenarios BS1 and BS2 (Fig. 1). Under both baseline scenarios BS3 and BS4, 33.5% of woodlands in 2010 were lost until 2030 (90,000 km^2), and croplands almost doubled during that period (Fig. 1). *BS3* showed strong cropland expansion in deforestation frontiers, especially in the south of Salta, Tucuman and Chaco provinces (Fig. 2), as well as a drastic grazing land expansion in Santiago del Estero. Similarly, agricultural intensification occurred clustered in Buenos Aires, La Pampa, Cordoba, Santa Fe and Entre Rios. Assuming yield increase as in BS2 (*BS4*) translated into more concentrated patterns of cropland expansion compared to *BS3,* which translated into woodlands in marginal regions (such as in Chaco or Entre Rios) being spared. Grazing land expansion in Santiago del Estero was even more drastic than in *BS3*.

3.2. Impact of economic policy interventions on future land use

Although our policy interventions overall resulted in similar general land-use conversions trajectories, important differences in the spatial patterns of land-use change occurred depending on the magnitude of the simulated land-use change and the type of policy intervention. Comparing future land-use change of our baseline scenarios 1 (*BS1*) and 2 (*BS2*) to those considering policy interventions showed that the impact of these policies on altering future land use was lower than expected under the scenarios assuming only profit-maximizing actors. Policies leading to decreasing (PI-1) or increasing *(PI-2)* agricultural profits resulted in similar overall trends of agricultural expansion and intensification compared to the baseline scenarios. *PI-1* and *PI-2* differed in the spatial patterns of land-use change though, as cropland expansion occurred less clustered under policies that would decrease profits (*PI-1*) compared to the baseline scenarios (*BS1* and *BS2*), whereas under policies that would increase profits (*PI-2*) cropland expansion patterns were more clustered. Paving roads in the future, for enhancing the connection of provincial capitals or towns (*PI-3 and PI-4)*, translated into a small increase in woodland conversion in marginal regions, such as the case of northern Salta.

Assuming land-use conversions continued at the rates of 2000–2010 (*BS3* and *BS4;* i.e., higher rates than in BS1 and BS2) increased the impact of our policy interventions. Decreasing cropland and grazing profits by 50% (*PI-1*) resulted into less woodland to cropland conversions in marginal regions of Santiago del Estero and Chaco. Yet, cropland expanded on grazing land in western Santa Fe and grazing land expanded on woodland in northern Santiago del Estero compared to the baseline *BS3* (Fig. 3). Increasing agricultural profits by 50% (*PI-2*) resulted in more agricultural intensification in western Santa Fe, while sparing some woodland in marginal regions such as south-eastern Salta or the north of Santiago. There was also less intensification in southern Buenos Aires compared to the baseline BS3 (Fig. 3).

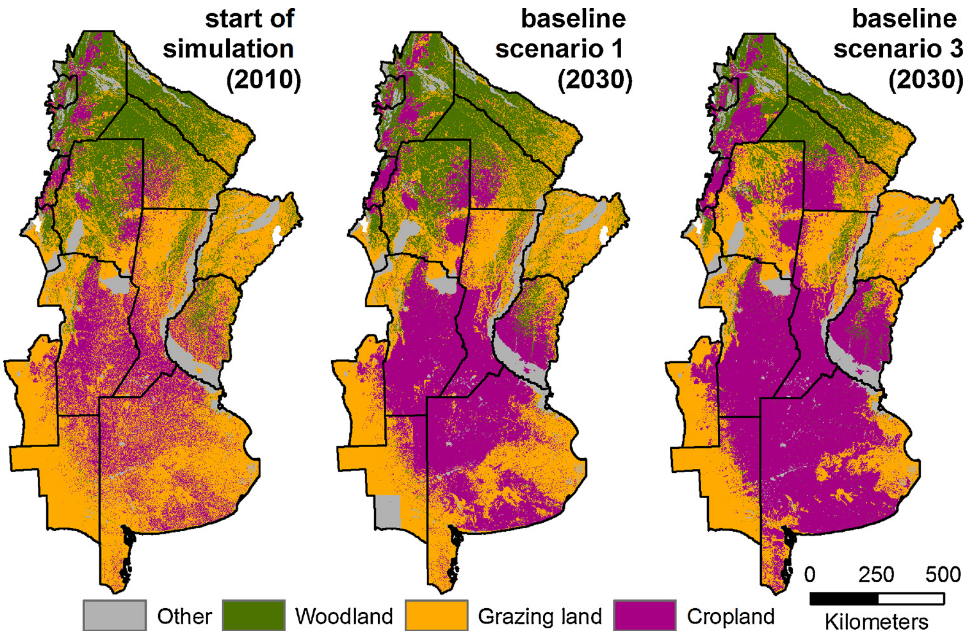

Fig. 2. Future land-use patterns in baseline scenarios 1 (BS1) and 3 (BS3) and start of simulation land use/cover (2010).

Road improvements (*PI-3* and *PI-4*) affected land-use change patterns substantially. When focusing on connecting provincial capitals with agricultural frontiers (*PI 3*), grazing land expanded into woodlands in northern Santiago del Estero, cropland expanded into woodlands in south-eastern Salta, and grazing land intensified to cropland in eastern Chaco and in western Santa Fe when compared to *BS3* (Fig. 3). Assuming infrastructure investments to better connect larger towns to export hubs (*PI-4*), we observed less woodland conversion in the east of Salta and the north of Santiago compared to the baseline scenario (*BS3*). Yet, agriculture intensified in western Santa Fe compared to BS3 (Fig. 3). Testing these policies when assuming yield increases (*BS4*) showed that there was a general trend towards cropland expansion into woodlands (such as in Entre Rios, Chaco or Salta), except in more marginal regions (such as east of Salta or western Chaco).

3.3. *Identifying areas with high agricultural conversion pressure*

Comparing all our 20 scenarios highlighted some particularly dynamic regions that experienced conversions under most of the scenarios (Fig. 4). These regions are primarily located in the south of Salta province (around the town Joaquin V. Gonzalez), the south of Chaco province (around the towns of Pampa del Infierno and Charata), the center and north of Santiago del Estero province (around the town Quimili), the west of Santa Fe province (around the town Tostado), the south of Entre Rios (around the town of Villaguay) and the center and south of Buenos Aires province (around the towns of Chascomus, Rauch, and Olavarria; Fig. 4).

Comparing these areas of high conversion probability to the conservation priority areas highlighted nineteen areas of conservation concern with particularly high land-use pressure (Fig. S3, Supplementary Material D). Fifteen of these areas belonged to the Chaco according to the priority areas of The Nature Conservancy (TNC, 2005): *Transición Chaco-Yungas, Bañados del Quirquincho, Zona del impenetrable, Derrames de los ríos Hornones y Ureña, Bañados del río Salado y Bañados de Figueroa, Bosques del límite Santiago del Estero-Chaco, Bosques del Este de Suncho Corral, Planicie aluvial del río Bermejo, Esteros salobres del norte de Santiago del Estero, Área del límite entre Tucumán y Santiago del Estero, Delta del Rio Dulce, Los Bajos submeridionales, Región*

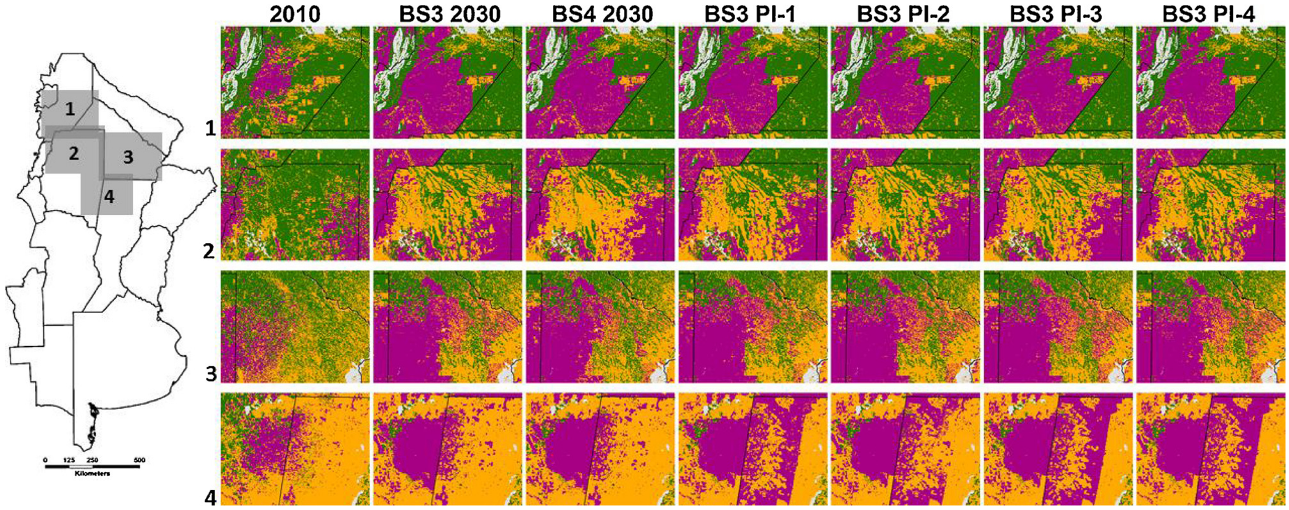

Fig. 3. Detail of spatial economic scenarios in 2030 in the Chaco under the forecast of historical land-use conversions as in 2000–2010. BS: baseline scenario, PI: policy intervention.

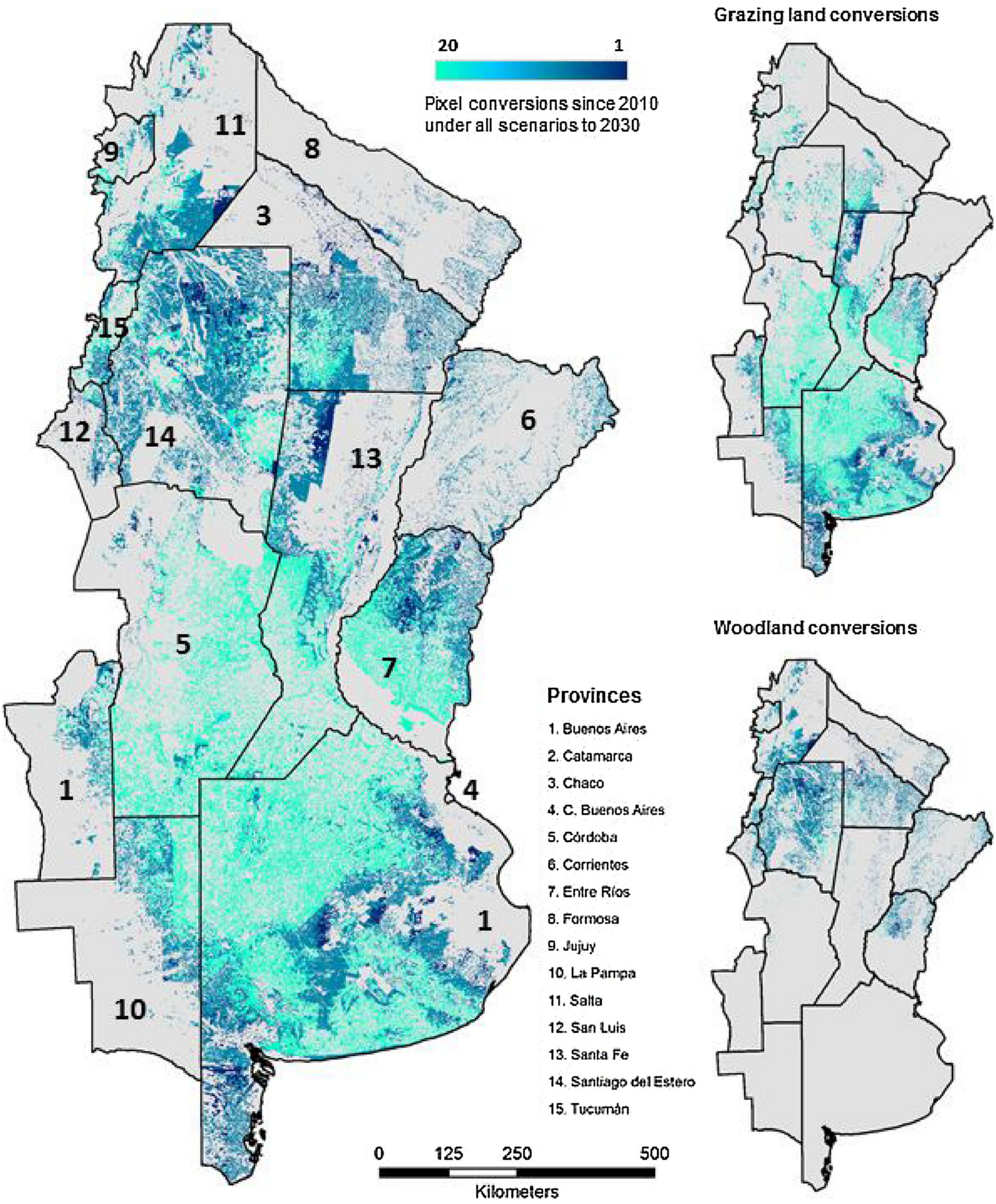

Fig. 4. Frequency of agricultural land-use conversions across all baseline scenarios (BS1, BS2, BS3, BS4) and policies incentives simulated (PI-1, PI-2, PI-3, PI-4).

del Iberá y Ñeembucú, Salinas Grandes, and *de Ambargasta y otras.* Four priority areas belonged to the Pampas according to the Valuable Pasture Areas (Bilenca and Miñarro, 2002): *Cuenca de Laguna la Picasa, Pajonales de paja colorada de la pampa deprimida, Cerrilladas- Llanura periserrana del Sistema de Tandilla, and Pastizales del Chasico-Villa Iris.*

4. Discussion

Understanding how future agricultural land-use patterns might change and how policies may affect these changes is important in light of the environmental trade-offs of agriculture and the increasing future demand for agricultural products (Angelsen, 2010; Schmitz et al., 2014). Here we explored potential future agricultural land-use scenarios in northern Argentina under diverging economic policies and identified areas where land-use pressure on conservation priority areas may be high. Our study provides five major insights. First, assuming that land users maximize profits, agricultural land-use change in the Chaco, Espinal and Pampas would shift onto an intensification pathway, with deforestation slowing down considerably. Second, these trends were not very sensitive to profit-related policy interventions, suggesting that the power of such policies (e.g., taxes, subsidies) in influencing future agricultural land-use patterns in Argentina's agricultural frontiers may be lower than assumed. Third, road improvement, especially to provincial capitals, would create strong incentives for agricultural expansion into forest. Fourth, our results suggest that the impact of policy interventions varies regionally, and was strongest in regions with a long agricultural history. Fifth, many priority areas for conservation may need protection in the future because they are very likely to experience high land-use pressure.

Our baseline scenarios assuming profit maximizing land users (*BS1* and *BS2*) showed little agricultural expansion, but a trend towards agricultural intensification. From a profit-maximizing perspective this makes sense, as it is much more profitable to converting grazing lands into croplands compared to converting woodlands into croplands, as the latter is much more capital intensive and dependent on environmental characteristics (Dalla-Nora et al., 2014; Henderson et al., 2013; Piquer-Rodríguez et al., 2018). Still, these overall lower-than-expected conversion rates were somewhat surprising, given high woodland conversion rates in the past. This provides further evidence that factors besides those affecting marginal profits appear to drive land-use decisions in the Chaco (e.g., cultural values ascribed to forests by indigenous communities, land acquisitions to ensure land access, or agglomeration economies) (Garrett et al., 2013; Gasparri et al., 2015; Henderson et al., 2013). Furthermore, we found that agricultural intensification occurred in a clustered way, suggesting a progressing frontier outwards from areas of already high agricultural intensity (Fig. 2). This was expected, as neighborhood relationships are an important factor explaining land conversions in the region (Piquer-Rodríguez et al., 2018; Volante et al., 2016), and established centers of agriculture are characterized by an accumulation of capital, better infrastructure, and technology (Krugman, 1991; Porter, 1998). In such regions (e.g., the Pampas region and the *Anta* and *Charata* regions in the Chaco), land users can react rapidly to new economic opportunities and our simulations show that intensification from cattle ranching to cropping would occur there quickly. Conversely, marginal regions far away from facilities and markets do respond slower to economic incentives to convert to cropping.

Future land conversion trends and patterns were overall fairly unaffected by policy interventions – even under strong policy assumptions. The low sensitivity of land-use change to these policies can be explained by two factors. First, the economic incentive to convert the land compared to maintaining woodland is very high for both agricultural activities (cropland or grazing) and thus small changes in profits may have little influence in land conversions since it is already very profitable to invest. Second, our results suggest a range of other factors not included in our NRM influencing land conversions (see above) which may impact future conversions in more diverging land-use trajectories (Garrett et al., 2013; Gasparri et al., 2015; Gasparri and le Polain de Waroux, 2015; Henderson et al., 2013). Our study provides further evidence for the often lower-than-expected power that economic policy interventions, such as taxes or subsidies, may have in influencing strategic land use changes, similar to what was found for the United States (Lawler et al., 2014; Radeloff et al., 2012) or Europe (Stürck et al., 2015).

The impact of our policy interventions was larger when extrapolating historical land-use change rates (BS3 and BS4), which had higher magnitude of change than scenarios BS1 and BS2. Exploring the effect of policies that would decrease agricultural profits (PI-1) resulted in less cropland expansion into marginal areas, a pattern that can be expected as land rents would be lowered particularly in such areas, or in areas with longer agricultural history where investments into intensification are less likely under lower profits (Fig. 3). At the same time, however, other areas nearby existing agriculture experienced higher woodland to grazing land conversions. One rationale explaining this is the fact that agricultural actors may use their profits to secure land rights and establish grazing lands, which is less costly and less affected by climate variability than croplands (Houspanossian et al., 2016; Murray et al., 2016), during times when profits are lower (Gasparri and le Polain de Waroux, 2015). To the contrary, increasing profits from agriculture (PI-2), for example through lowering taxes, suggests agricultural intensification would increase forming denser clusters of cropland, since agricultural intensification in our study region is very responsive to marginal profit changes (Piquer-Rodríguez et al., 2018). Lastly, our road development scenarios (PI-3 and PI-4) highlight the importance of provincial capitals as regional hubs for agriculture, similar to other regions in the world (Ferretti-Gallon and Busch, 2014; Leblois et al., 2017). This suggests that future infrastructure developments plans of Argentina (e.g. *Plan Belgrano*) should be implemented carefully, as they may promote agricultural expansion (Camara Argentina de la Construccion et al., 2000), especially nearby existing agricultural areas.

Overall, important and coherent regional variations emerged from all scenarios analyzed. For example, policies increasing profits may have the potential to spare forests in marginal regions, if accompanied by adequate protection of forests, as intensification in core agricultural areas already under intensive production would be favored (assuming full flexibility of land users). Conversely, policies lowering profits, could result in an expansion of grazing land into more marginal areas, consistent with the theory that land users would seek to secure land for future agricultural development in such periods (Gasparri and le Polain de Waroux, 2015). Accounting for technological innovation (i.e., yield increases) also had marked regional effects, potentially lowering the loss of woodland in marginal regions. Yet, interestingly, yield increases could also act as an incentive to further expand cropland (e.g., south of Salta or north of Santiago) as suggested for other regions (Garrett et al., 2013; Rudel et al., 2009). Such a spatial reorganization is common where agriculture industrializes (Byerlee et al., 2014; Kuemmerle et al., 2016).

An important regional finding from our simulations was that many areas within the Argentinian Pampas and Chaco regions are likely to experience future agricultural land-use change, regardless of the scenarios and policy interventions investigated (Fig. 4), including many areas of conservation concern (Fig. S3). This was the case, for example, for Buenos Aires, the north of Santiago del Estero, southern Salta, southern Cordoba, Entre Rios and south-western Chaco. The fairly small effect that the diverse policies we investigated had on steering land conversions away from sensitive areas suggests that zoning, or new protected areas, are potentially more powerful tool for that purpose, if properly implemented and enforced. Given the many areas of conservation concern that would be affected by future land-use changes (Fig. S3), careful, proactive conservation planning is needed (Kuemmerle et al., 2017). Conversely, other areas will experience low land-use change pressure under all policy interventions, such as San Luis, Catamarca or Formosa, potentially highlighting areas that were not responsive to factors influencing conversions included in our model.

Our simulation approach is not without limitations. First, our NRM assumes that actors maximize profits, although there may be other factors influencing land-use conversions regionally, such as social and cultural aspects (e.g., attachment to land or traditional land uses), land zonation that restrict uses or other socio-economic factors such as access to capital, land speculation, securing land rights or knowledge diffusion (Garrett et al., 2013; Gasparri et al., 2015; Gasparri and le Polain de Waroux, 2015; Piquer-Rodríguez et al., 2018; Richards, 2018). However, given the strong presence of agri-business actors in Argentina, who have a strong focus on profit maximization (Le Polain de Waroux et al., 2018), we believe our models are a good approximation of decision making in this area. Second, our NRM is a partial equilibrium model. That is, changes in profit to land owners only influence decisions at the margin, but do not feedback on the entire economy. For example, in the scenarios where profit increases, the conversion likelihood changes only through changes in land rent. In reality, if wealth accumulates, this alone may influence land user's decisions by changing landowner access to capital and their capacity to invest into other economic sectors. Such dynamics are not included in our model. Also, our model covers a period with considerable economic perturbations in Argentina, suggesting that land owners had less capacity to react to economic incentives then they would during more stable times. Third, we do not directly account for transaction cost in our model, and these cost may vary over our study area. Generally, Argentina has well-functioning land markets where transaction costs are relatively low. However, in frontier regions, where land tenure may not be well documented, transaction cost can be high (Le Polain de Waroux et al., 2018), and we were unable to account for this directly in our model due to the lack of data on transaction cost in our study area. However, if the variation in transaction costs occurs primarily across provinces rather than within provinces, transaction cost will be controlled for in the province level dummy variable of the NRM (*province*, see Supp. Material B– Eq. (1)). Fourth, the model used here was parametrized for the entire region and, as such, did not include the influence of provincial policies. This might explain, for example, why we did not project any further grazing land expansion in eastern Salta, which is environmentally suitable for ranching and provincial zoning permits sustainable grazing activities, since grazing land expansion was located in regions of better suitability outside Salta. Fifth, we considered provincial and national protected areas to be effective in restricting land-use expansion, in line with recent evidence (Greenpeace, 2016; Marinaro et al., 2012). However, this may change as the competition for land increases, as in other tropical regions (Laurance et al., 2012). Sixth, some regions had lower-than-expected conversions rates and this might be explained by the strong presence of indigenous communities, such as in Salta or Formosa. Another factor explaining the relative stability of Formosa province is that this agricultural frontier has only recently been activated, following the paving of road 81 in 2008, the last two years in our model parametrization period. Finally, having farm-level profit information would likely capture more of the spatial variation in our study area and thus improve our models. Such data, however, are not available for the Chaco. Similarly, modelling land-use change at the level of cadastral plots would likely result in even more realistic fine-scale land-use change patterns.

5. Conclusion

Understanding future land-use patterns and how policies may alter them is important for avoiding the unwanted outcomes of agricultural expansion and intensification. Using a spatial net returns model, we analyzed how land-use change in northern Argentina is driven by factors affecting profit, and provided evidence for the impact of some economic policy interventions (including infrastructure development) on future land-use change patterns. Overall, when assuming profit-maximizing land-use actors, we find land-use change mainly to occur via agricultural intensification, while agricultural expansion into forest should slow down. Policies increasing profits might lower deforestation in marginal regions to some extent, but the overall impact of these policies was lower-than-expected. Our simulations also highlighted that factors other than profit-maximization are drivers of agricultural expansion in the Chaco, further cautioning against overestimating the impact of economic policies on rates and spatial patterns of deforestation. Our study also highlights that many areas of conservation priority will continue to receive high conversion pressure in the future, enforcing the need for ramping up conservation actions. Area-based policies, such as zoning, as already in place, and the expansion of Argentina's protected area network, are likely more powerful and less risky tools for avoiding further loss and degradation of these areas of conservation concern – provided that zoning and protected area regulations are properly enforced. At a more general level, our study shows how evaluating potential future impacts of economic policies on land-use change may inform land-use planning in current and future agricultural frontiers in the global South.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.landusepol.2018.07.039.

References

Adamoli, J., Ginzburg, R., Torrella, S., 2011. Escenarios productivos y ambientales del Chaco Argentino. 1977–2010. Fundación Producir Conservando // GESEAA-UBA p. 101.

Akaike, H., 1973. Information theory and an extension of the maximum likelihood principle. In: Petrov, B.N., Caski, F. (Eds.), International Symposium on Information Theory. Akademiai Kiado, Budapest, pp. 267–281.

Angelsen, A., 2010. Policies for reduced deforestation and their impact on agricultural production. Proc. Natl. Acad. Sci. 107, 19639–19644.

Arima, E.Y., 2016. A spatial probit econometric model of land change: the case of infrastructure development in Western Amazonia, Peru. PLoS One 11, e0152058.

Assunção, J., Gandour, C., Rocha, R., Rocha, R., 2013. Does Credit Affect Deforestation? Climate policy initiative, Rio de Janeiro p. 50.

Baldi, G., Guerschman, J.P., Paruelo, J.M., 2006. Characterizing fragmentation in temperate South America grasslands. Agric. Ecosyst. Environ. 116, 197–208.

Barbier, E.B., 2012. Scarcity, frontiers and development. Geogr. J. 178, 110–122.

Baumann, M., Gasparri, I., Piquer-Rodríguez, M., Gavier Pizarro, G., Griffiths, P., Hostert, P., Kuemmerle, T., 2016a. Carbon emissions from agricultural expansion and intensification in the Chaco. Glob. Change Biol. 23 (5), 1902–1916. https://doi.org/10.1111/gcb.13521.

Baumann, M., Piquer-Rodríguez, M., Fehlenberg, V., Gavier Pizarro, G., Kuemmerle, T., 2016b. Land-use competition in the South-American Chaco. In: Niewöhner, J., Bruns, A., Hostert, P., Krueger, T., Nielsen, J.Ø., Haberl, H., Lauk, C., Lutz, J., Müller, D. (Eds.), Land Use Competition: Ecological, Economic and Social Perspectives. Springer p. 370.

Baumann, M., Israel, C., Piquer-Rodríguez, M., Gavier Pizarro, G., Volante, J.N., Kuemmerle, T., 2017. Deforestation and cattle expansion in the Paraguayan Chaco 1987–2012. Reg. Environ. Change 17 (4), 1179–1191. https://doi.org/10.1007/s10113-10017-11109-10115.

Bert, F.E., Podestá, G.P., Rovere, S.L., Menéndez, Á.N., North, M., Tatara, E., Laciana, C.E., Weber, E., Toranzo, F.R., 2011. An agent based model to simulate structural and land use changes in agricultural systems of the argentine pampas. Ecol. Modell. 222, 3486–3499.

Bilenca, D., Miñarro, F., 2002. Areas Valiosas de Pastizal: en las Pampas y Campos de Argentina, Uruguay y Sur de Brasil. Fundacion Vida Silvestre Argentina 353 pp.

Bockstael, N.E., 1996. Modeling economics and ecology: the importance of a spatial perspective. Am. J. Agric. Econ. 78, 1168–1180.

Bortolín, D., 2015. Plan inversión vial 2016–2025. p. 93. .

Burkart, R., Bárbaro, N.O., Sánchez, R.O., Gómez, D.A., 1999. In: Nacionales, A.d.P. (Ed.), Eco-regiones de la Argentina. Secreataría de Recursos Naturales y Desarrollo Sustentable. Presidencia de la Nación p. 21.

Butsic, V., Lewis, D.J., Radeloff, V.C., 2010. Lakeshore zoning has heterogeneous ecological effects: an application of a coupled economic-ecological model. Ecol. Appl. 20, 867–879.

Butsic, V., Lewis, D.J., Ludwig, L., 2011. An econometric analysis of land development with endogenous zoning. Land Econ. 87, 412–432.

Byerlee, D., Stevenson, J., Villoria, N., 2014. Does intensification slow crop land expansion or encourage deforestation? Glob. Food Sec. 3, 92–98.

Cabrera, A.L., 1971. Fitogeografía de la República Argentina. Boletín de la Sociedad Argentina de Botánica 14, 43.

Camara Argentina de la Construccion, Centro Argentino de Ingenieros, Camara Argentina de Consultores, Asociacion Argentina de Carreteras, 2000. Infraestructura Siglo XXI–Plan Infraestructura, Carreteras. p. 68. .

Canosa, F.R., Feldkamp, C.R., Urruti, J., Morris, M., M.R.M, 2013. Potencial de la producción ganadera Argentina ante diferentes escenarios. Fundación Producir Conservando p. 82.

Choumert, J., Phélinas, P., 2015. Determinants of agricultural land values in Argentina. Ecol. Econ. 110, 134–140.

CIARA, 2017. Liquidacion de Divisas. Camara de la Industria Aceitera de la Republica Argentina. Centro de Exportadores de Cereales, Buenos Aires, Argentina.

Corral, J., Arbeletche, P., Burges, J.C., Morales, H., Continanza, G., Courderc, J., Courdin, V., 2008. Clermont-Ferrand (France). Multi-Agent Systems Applied to Land Use and Social Changes in Río De La Plata Basin (South America) 8th European IFSA Symposium 621–631.

Dalla-Nora, E.L., de Aguiar, A.P.D., Lapola, D.M., Woltjer, G., 2014. Why have land use change models for the Amazon failed to capture the amount of deforestation over the last decade? Land Use Policy 39, 403–411.

Fernández, D.A., 2014. On the Homogenization of the Tax Burden on the Pampas Agriculture That Followed Devaluation. Mundo agrario, pp. 15.

Ferretti-Gallon, K., Busch, J., 2014. What Drives Deforestation and What Stops It? A Meta-Analysis of Spatially Explicit Econometric Studies. Center for Global Development p. 44.

Foley, J.A., Ramankutty, N., Brauman, K.A., Cassidy, E.S., Gerber, J.S., Johnston, M., Mueller, N.D., O'Connell, C., Ray, D.K., West, P.C., Balzer, C., Bennett, E.M., Carpenter, S.R., Hill, J., Monfreda, C., Polasky, S., Rockstrom, J., Sheehan, J., Siebert, S., Tilman, D., Zaks, D.P.M., 2011. Solutions for a cultivated planet. Nature 478, 337–342.

Garrett, R.D., Lambin, E.F., Naylor, R.L., 2013. The new economic geography of land use change: supply chain configurations and land use in the Brazilian Amazon. Land Use Policy 34, 265–275.

Gasparri, N.I., Grau, H.R., 2009. Deforestation and fragmentation of Chaco dry forest in NW Argentina (1972–2007). For. Ecol. Manage. 258, 913–921.

Gasparri, N.I., le Polain de Waroux, Y., 2015. The coupling of South American soybean and cattle production frontiers: new challenges for conservation policy and land change science. Conserv. Lett. 8, 290–298.

Gasparri, N.I., Grau, H.R., Gutiérrez Angonese, J., 2013. Linkages between soybean and neotropical deforestation: coupling and transient decoupling dynamics in a multi-decadal analysis. Glob. Environ. Change Part A 23, 1605–1614.

Gasparri, N.I., Grau, H.R., Sacchi, L.V., 2015. Determinants of the spatial distribution of cultivated land in the North Argentine Dry Chaco in a multi-decadal study. J. Arid Environ. 123, 31–39.

Gavier-Pizarro, G., Calamari, N., Piquer-Rodríguez, M., Kuemmerle, T., 2014. Scenario analysis applied to landscape planning (El método de construcción de escenarios aplicado al ordenamiento territorial). In: Paruelo, J., Jobbágy, E., Laterra, P., Dieguez, H., García Collazo, M., Panizza, A. (Eds.), Landscape Planning: Conceps, Methods and Experiences (Ordenamiento Territorial: Conceptos, Metodologías y Experiencias). FAO / MAG / UBA, Buenos Aires, pp. 217–240.

Geist, H.J., Lambin, E.F., 2002. Proximate causes and underlying driving forces of tropical deforestation. Bioscience 52, 143–150.

González-Roglich, M., Swenson, J.J., Villarreal, D., Jobbágy, E.G., Jackson, R.B., 2015. Woody plant-cover dynamics in Argentine Savannas from the 1880s to 2000s: the interplay of encroachment and agriculture conversion at varying scales. Ecosystems 18, 481–492.

Grau, H.R., Torres, R., Gasparri, N.I., Blendinger, P.G., Marinaro, S., Macchi, L., 2015. Natural grasslands in the Chaco. A neglected ecosystem under threat by agriculture expansion and forest-oriented conservation policies. J. Arid Environ. 123, 40–46.

Greenpeace, 2016. Deforestación en el norte de Argentina. p. 7. .

Henderson, K.A., Anand, M., Bauch, C.T., 2013. Carrot or stick? Modelling how landowner behavioural responses can cause incentive-based forest governance to backfire. PLoS One 8, e77735.

Herrera, L., Nabinger, C., Weyland, F., Parera, A., 2014. Caracterización de los Pastizales del Cono Sur, servicios ecosistémicos y problemática actual de conservación. In: Parera, A., Paullier, I., Weyland, F. (Eds.), Índice de Contribución a la Conservación de Pastizales Naturales del Cono Sur: una herramienta para incentivar a los productores rurales, first ed. pp. 21–39 Aves Uruguay.

Houspanossian, J., Giménez, R., Baldi, G., Nosetto, M., 2016. Is aridity restricting deforestation and land uses in the South American Dry Chaco? J. Land Use Sci. 11, 369–383.

Hu, B., Palta, M., 2006. Pseudo-r2 in logistic regression model. Stat. Sin. 16, 847–860.

Krugman, P., 1991. Increasing returns and economic geography. J. Polit. Econ. 99, 483–499.

Kuemmerle, T., Levers, C., Erb, K., Estel, S., Jepsen, M.R., Müller, D., Plutzar, C., Stürck, J., Verkerk, P.J., Verburg, P.H., Reenberg, A., 2016. Hotspots of land use change in Europe. Environ. Res. Lett. 11, 064020.

Kuemmerle, T., Altrichter, M., Baldi, G., Cabido, M., Camino, M., Cuellar, E., Cuellar, R.L., Decarre, J., Díaz, S., Gasparri, I., Gavier-Pizarro, G., Ginzburg, R., Giordano, A.J., Grau, H.R., Jobbágy, E., Leynaud, G., Macchi, L., Mastrangelo, M., Matteucci, S.D., Noss, A., Paruelo, J., Piquer-Rodríguez, M., Romero-Muñoz, A., Semper-Pascual, A., Thompson, J., Torrella, S., Torres, R., Volante, J.N., Yanosky, A., Zak, M., 2017. Forest conservation: remember Gran Chaco. Science 355 465–465.

Lambin, E.F., Gibbs, H.K., Ferreira, L., Grau, R., Mayaux, P., Meyfroidt, P., Morton, D.C., Rudel, T.K., Gasparri, I., Munger, J., 2013. Estimating the world's potentially available cropland using a bottom-up approach. Glob. Environ. Change Part A 23, 892–901.

Laurance, W.F., Carolina Useche, D., Rendeiro, J., Kalka, M., Bradshaw, C.J.A., Sloan, S.P., Laurance, S.G., Campbell, M., Abernethy, K., Alvarez, P., Arroyo-Rodriguez, V., Ashton, P., Benitez-Malvido, J., Blom, A., Bobo, K.S., Cannon, C.H., Cao, M., Carroll, R., Chapman, C., Coates, R., Cords, M., Danielsen, F., De Dijn, B., Dinerstein, E., Donnelly, M.A., Edwards, D., Edwards, F., Farwig, N., Fashing, P., Forget, P.-M., Foster, M., Gale, G., Harris, D., Harrison, R., Hart, J., Karpanty, S., John Kress, W., Krishnaswamy, J., Logsdon, W., Lovett, J., Magnusson, W., Maisels, F., Marshall, A.R., McClearn, D., Mudappa, D., Nielsen, M.R., Pearson, R., Pitman, N., van der Ploeg, J., Plumptre, A., Poulsen, J., Quesada, M., Rainey, H., Robinson, D., Roetgers, C., Rovero, F., Scatena, F., Schulze, C., Sheil, D., Struhsaker, T., Terborgh, J., Thomas, D., Timm, R., Nicolas Urbina-Cardona, J., Vasudevan, K., Joseph Wright, S., Carlos Arias, G.J., Arroyo, L., Ashton, M., Auzel, P., Babaasa, D., Babweteera, F., Baker, P., Banki, O., Bass, M., Bila-Isia, I., Blake, S., Brockelman, W., Brokaw, N., Bruhl, C.A., Bunyavejchewin, S., Chao, J.-T., Chave, J., Chellam, R., Clark, C.J., Clavijo, J., Congdon, R., Corlett, R., Dattaraja, H.S., Dave, C., Davies, G., de Mello Beisiegel, B., de Nazare Paes da Silva, R., Di Fiore, A., Diesmos, A., Dirzo, R., Doran-Sheehy, D., Eaton, M., Emmons, L., Estrada, A., Ewango, C., Fedigan, L., Feer, F., Fruth, B., Giacalone Willis, J., Goodale, U., Goodman, S., Guix, J.C., Guthiga, P., Haber, W., Hamer, K., Herbinger, I., Hill, J., Huang, Z., Fang Sun, I., Ickes, K., Itoh, A., Ivanauskas, N., Jackes, B., Janovec, J., Janzen, D., Jiangming, M., Jin, C., Jones, T., Justiniano, H., Kalko, E., Kasangaki, A., Killeen, T., King, H.-b., Klop, E., Knott, C., Kone, I., Kudavidanage, E., Lahoz da Silva Ribeiro, J., Lattke, J., Laval, R., Lawton, R., Leal, M., Leighton, M., Lentino, M., Leonel, C., Lindsell, J., Ling-Ling, L., Eduard Linsenmair, K., Losos, E., Lugo, A., Lwanga, J., Mack, A.L., Martins, M., Scott McGraw, W., McNab, R., Montag, L., Myers Thompson, J., Nabe-Nielsen, J., Nakagawa, M., Nepal, S., Norconk, M., Novotny, V., O'Donnell, S., Opiang, M., Ouboter, P., Parker, K., Parthasarathy, N., Pisciotta, K., Prawiradilaga, D., Pringle, C., Rajathurai, S., Reichard, U., Reinartz, G., Renton, K., Reynolds, G., Reynolds, V., Riley, E., Rodel, M.-O., Rothman, J., Round, P., Sakai, S., Sanaiotti, T., Savini, T., Schaab, G., Seidensticker, J., Siaka, A., Silman, M.R., Smith, T.B., de Almeida, S.S., Sodhi, N., Stanford, C., Stewart, K., Stokes, E., Stoner, K.E., Sukumar, R., Surbeck, M., Tobler, M., Tscharntke, T., Turkalo, A., Umapathy, G., van Weerd, M., Vega Rivera, J., Venkataraman, M., Venn, L., Verea, C., Volkmer de Castilho, C., Waltert, M., Wang, B., Watts, D., Weber, W., West, P., Whitacre, D., Whitney, K., Wilkie, D., Williams, S., Wright, D.D., Wright, P., Xiankai, L., Yonzon, P., Zamzani, F., 2012. Averting biodiversity collapse in tropical forest protected areas. Nature 489, 290–294.

Laurance, W.F., Sayer, J., Cassman, K.G., 2014. Agricultural expansion and its impacts on tropical nature. Trends Ecol. Evol. 29, 107–116.

Lawler, J.J., Lewis, D.J., Nelson, E., Plantinga, A.J., Polasky, S., Withey, J.C., Helmers, D.P., Martinuzzi, S., Pennington, D., Radeloff, V.C., 2014. Projected land-use change impacts on ecosystem services in the United States. Proc. Natl. Acad. Sci. 111, 7492–7497.

le Polain de Waroux, Y., Garrett, R.D., Heilmayr, R., Lambin, E.F., 2016. Land-use policies and corporate investments in agriculture in the Gran Chaco and Chiquitano. Proc. Natl. Acad. Sci. 113 (15), 4021–4026.

Le Polain de Waroux, Y., Baumann, M., Gasparri, I., Gavier Pizarro, G., Godar, J., Kuemmerle, T., Müller, R., Vázquez, F., Volante, J., Meyfroidt, P., 2018. Rents, actors, and the expansion of commodity frontiers in the Gran Chaco. Ann. Am. Assoc. Geogr. 108.

Leblois, A., Damette, O., Wolfersberger, J., 2017. What has driven deforestation in developing countries since the 2000s? Evidence from new remote-sensing data. World Dev. 92, 82–102.

Leguizamón, A., 2014. Modifying Argentina: GM soy and socio-environmental change. Geoforum 53, 149–160.

Leguizamón, A., 2016. Disappearing nature? Agribusiness, biotechnology and distance in Argentine soybean production. J. Peasant Stud. 43, 313–330.

Lewis, D.J., Plantinga, A.J., 2007. Policies for habitat fragmentation: combining econometrics with GIS-based landscape simulations. Land Econ. 83, 109–127.

Macchi, L., Grau, H.R., Zelaya, P.V., Marinaro, S., 2013. Trade-offs between land use intensity and avian biodiversity in the dry Chaco of Argentina: a tale of two gradients. Agric. Ecosyst. Environ. 174, 11–20.

Macedo, M.N., DeFries, R.S., Morton, D.C., Stickler, C.M., Galford, G.L., Shimabukuro, Y.E., 2012. Decoupling of deforestation and soy production in the southern Amazon during the late 2000s. Proc. Natl. Acad. Sci. 109, 1341–1346.

MAGyP, 2011. Plan Estratégico Agroalimentario y Agroindustrial, Participativo y Federal. Ministerio de Agricultura, Ganadería y Pesca de la Nación. Argentina, Buenos Aires, Argentina p. 161.

Marinaro, S., Grau, H.R., Aráoz, E., 2012. Extensión y originalidad en la creación de parques nacionales en relación a cambios gubernamentales y económicos de la Argentina. Ecología austral 22, 1–10.

Marinaro, S., Grau, H.R., Gasparri, I.N., Kuemmerle, T., Baumann, M., 2017. Differences in production, carbon stocks and biodiversity outcomes of land tenure regimes in the Argentine Dry Chaco. Environ. Res. Lett. 12 (4), 045003.

Mastrangelo, M.E., Gavin, M.C., 2014. Impacts of agricultural intensification on avian richness at multiple scales in Dry Chaco forests. Biol. Conserv. 179, 63–71.

Maxwell, S.L., Fuller, R.A., Brooks, T.M., Watson, J.E.M., 2016. Biodiversity: the ravages of guns, nets and bulldozers. Nature 536, 143–145.

Meller, P., 1994. The Chilean trade liberalization and export expansion process 1974–90. In: Helleiner, G. (Ed.), Trade Policy and Industrialization in Turbulent Times. Routledge, London p. 554.

Meyfroidt, P., 2015. Approaches and terminology for causal analysis in land systems science. J. Land Use Sci. 1–27.

Meyfroidt, P., Carlson, K.M., Fagan, M.E., Gutiérrez-Vélez, V.H., Macedo, M.N., Curran, L.M., DeFries, R.S., Dyer, G.A., Gibbs, H.K., Lambin, E.F., Morton, D.C., Robiglio, V., 2014. Multiple pathways of commodity crop expansion in tropical forest landscapes. Environ. Res. Lett. 9, 074012.

Milburn, F., 2005. Use of scenarios in strategic and political risk analyses. Handb. Bus. Strategy 6 (1), 25–30. https://doi.org/10.1108/08944310510556919.

Morello, J., Matteucci, S.D., Rodriguez, A.F., Silva, M.E., 2012. Ecorregiones y complejos ecosistémicos argentinos. Facultad de Arquitectura Diseño y Urbanismo and Grupo de Ecologia de Paisaje y Medio Ambiente, Buenos Aires, Argentina.

Murray, F., Baldi, G., von Bernard, T., Viglizzo, E.F., Jobbágy, E.G., 2016. Productive performance of alternative land covers along aridity gradients: ecological, agronomic and economic perspectives. Agric. Syst. 149, 20–29.

Nepstad, D., McGrath, D., Stickler, C., Alencar, A., Azevedo, A., Swette, B., Bezerra, T., DiGiano, M., Shimada, J., Seroa da Motta, R., Armijo, E., Castello, L., Brando, P., Hansen, M.C., McGrath-Horn, M., Carvalho, O., Hess, L., 2014. Slowing Amazon deforestation through public policy and interventions in beef and soy supply chains. Science 344, 1118–1123.

Nolte, C., le Polain de Waroux, Y., Munger, J., Reis, T.N.P., Lambin, E.F., 2017. Conditions influencing the adoption of effective anti-deforestation policies in South America's commodity frontiers. Glob. Environ. Change Part A 43, 1–14.

OCDE/FAO, 2014. Perspectivas Agrícolas 2014–2023. OCDE.

Passaniti, M.V., 2011. Estudio del sector de ganado y carne vacunos argentino y políticas públicas (2000–2010). Universidad Católica Argentina p. 43.

Patrouilleau, R.D., Gallopin, G., Sosa, A.J., Angelucci, R., Saavedra, M., Carvalho, N., 2007. Las fuerzas que impulsan la evolución del futuro o los futuros de Argentina, Cuadernos de Desarrollo INTA. Unidad de Coyuntura y Prospectiva. p. 99. .

Patrouilleau, R.D., Saavedra, M., Patrouilleau, M.M., Gauna, D.H., 2012. Escenarios del Sistema Agoalimentario Argentino al 2030, Cuadernos de Prospectiva. INTA, Instituto de Investigación en Prospectiva y Politicas Públicas, Buenos Aires p. 116.

Pearce, J., Ferrier, S., 2000. Evaluating the predictive performance of habitat models developed using logistic regression. Ecol. Modell. 133, 225–245.

Pengue, W., 2014. Cambios y escenarios en la agricultura Argentina del siglo XXI. Fundación Heinrich Böll p. 49.

Peterson, G.D., Cumming, G.S., Carpenter, S.R., 2003. Scenario planning: a tool for conservation in an uncertain world. Conserv. Biol. 17, 358–366.

Piquer-Rodríguez, M., Torella, S., Gavier-Pizarro, G., Volante, J., Somma, D., Ginzburg, R., Kuemmerle, T., 2015. Effects of past and future land conversions on forest connectivity in the Argentine Chaco. Landsc. Ecol. 30, 817–833.

Piquer-Rodríguez, M., Butsic, V., Gärtner, P., Macchi, L., Baumann, M., Gavier Pizarro, G., Volante, J.N., Gasparri, I.N., Kuemmerle, T., 2018. Drivers of agricultural land-use change in the Argentine Pampas and Chaco regions. Appl. Geogr. 91, 111–122.

Plantinga, A.J., Lewis, D.J., 2014. Landscape simulation with econometric-based land-use models. In: Duke, J.M., Wu, J.J. (Eds.), The Oxford Handbook of Land Economics. Oxford University Press, New York, pp. 768.

Polasky, S., Carpenter, S.R., Folke, C., Keeler, B., 2011. Decision-making under great uncertainty: environmental management in an era of global change. Trends Ecol. Evol. 26, 398–404.

Porter, M., 1998. Clusters and the New Economics of Competition. Harvard Business Review, pp. 77–90.

Prado, D., 1993. What is the Gran Chaco vegetation in South America? A review. Contribution to the study of flora and vegetation of the Chaco. Candollea 48, 27.

Radeloff, V.C., Nelson, E., Plantinga, A.J., Lewis, D.J., Helmers, D., Lawler, J.J., Withey, J.C., Beaudry, F., Martinuzzi, S., Butsic, V., Lonsdorf, E., White, D., Polasky, S., 2012. Economic-based projections of future land use in the conterminous United States under alternative policy scenarios. Ecol. Appl. 22, 1036–1049.

Ramankutty, N., Foley, J.A., Norman, J., McSweeney, K., 2002. The global distribution of cultivable lands: current patterns and sensitivity to possible climate change. Glob. Ecol. Biogeogr. 11, 377–392.

Richards, P., 2018. It's not just where you farm; it's whether your neighbor does too. How agglomeration economies are shaping new agricultural landscapes. J. Econ. Geogr. 18, 87–110.

Rudel, T.K., Schneider, L., Uriarte, M., Turner, B.L., DeFries, R., Lawrence, D., Geoghegan, J., Hecht, S., Ickowitz, A., Lambin, E.F., Birkenholtz, T., Baptista, S., Grau, R., 2009. Agricultural intensification and changes in cultivated areas, 1970–2005. Proc. Natl. Acad. Sci. 106, 20675–20680.

Schmitz, C., van Meijl, H., Kyle, P., Nelson, G.C., Fujimori, S., Gurgel, A., Havlik, P., Heyhoe, E., d'Croz, D.M., Popp, A., Sands, R., Tabeau, A., van der Mensbrugghe, D., von Lampe, M., Wise, M., Blanc, E., Hasegawa, T., Kavallari, A., Valin, H., 2014. Land-use change trajectories up to 2050: insights from a global agro-economic model comparison. Agric. Econ. 45, 69–84.

Seo, S.N., 2009. Assessing relative performance of econometric models in measuring the impact of climate change on agriculture using spatial autoregression. Rev. Reg. Stud. 38 (2), 195–209 Southern Regional Science Association.

Spera, S.A., Galford, G.L., Coe, M.T., Macedo, M.N., Mustard, J.F., 2016. Land-use change affects water recycling in Brazil's last agricultural frontier. Glob. Change Biol. 22, 3405–3413.

Stürck, J., Levers, C., van der Zanden, E.H., Schulp, C.J.E., Verkerk, P.J., Kuemmerle, T., Helming, J., Lotze-Campen, H., Tabeau, A., Popp, A., Schrammeijer, E., Verburg, P., 2015. Simulating and delineating future land change trajectories across Europe. Reg. Environ. Change 1–17.

Tilman, D., Balzer, C., Hill, J., Befort, B.L., 2011. Global food demand and the sustainable intensification of agriculture. Proc. Natl. Acad. Sci. 108, 20260–20264.

TNC, 2005. Evaluación Ecoregional del Gran Chaco. The Nature Conservancy, South American Conservation Region, Buenos Aires p. 28.

Torres, R., Gasparri, N.I., Blendinger, P., Grau, H.R., 2014. Land-use and land-cover effects on regional biodiversity distribution in a subtropical dry forest: a hierarchical integrative multi-taxa study. Reg. Environ. Change 1–13.

Urcola, H.A., de Sartre, X.A., Veiga Jr, I., Elverdin, J., Albaladejo, C., 2015. Land tenancy, soybean, actors and transformations in the pampas: a district balance. J. Rural Stud. 39, 32–40.

Viglizzo, E.F., Frank, F.C., Carreño, L.V., Jobbágy, E.G., Pereyra, H., Clatt, J., Pincén, D., Ricard, M.F., 2011. Ecological and environmental footprint of 50 years of agricultural expansion in Argentina. Glob. Change Biol. 17, 959–973.

Volante, J.N., Mosciaro, M.J., Gavier-Pizarro, G.I., Paruelo, J.M., 2016. Agricultural expansion in the Semiarid Chaco: poorly selective contagious advance. Land Use Policy 55, 154–165.

WWF, 2006. WWF Lauds Paraguay for Slashing Deforestation 85 Percent. WWF.

WWF, 2015. Soy and Deforestation—The Gran Chaco. World Wildlife Fund.