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Drivers of agricultural land-use change in the Argentine Pampas and Chaco regions

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ABSTRACT

Agricultural expansion and intensification in South America's dry forests and grasslands increase agricultural production, but also result in major environmental trade-offs. The Pampas and Chaco regions of Argentina have been global hotspots of agricultural land-use change since the 2000s, yet our understanding of what drives the spatial patterns of these land-use changes remains partial. We parameterized a net returns model of agricultural land-use change to estimate the probability of agricultural expansion (conversions of woodlands to either cropland or grazing land) and agricultural intensification (conversion of grazing land to cropland) at the 1-km scale for the years 2000 and 2010. Uniquely, our model allowed us to quantify the importance of underlying causes (i.e., changes in agricultural profit) and spatial determinants (i.e., soil fertility, distance to markets, etc.), for Argentina's prime agricultural regions as a whole. We found that cropland and grazing land expansion into woodlands was much less sensitive to changes in profit-related factors than agricultural intensification. Profit-related variables, were a particularly strong cause of intensification in the Pampas, where cropland profits rose by 29% (compared to 18% in the Chaco). This suggests that further conversions of grazing land to cropland in the Pampas and Chaco is likely as long as agricultural demand, and thus returns to agriculture, continue to be high. The moderate impact of profit-related factors on affecting woodland conversion rates also suggests a limited potential of economic policies that affect marginal profits (e.g., taxes or subsidies) to alter deforestation rates and patterns in major ways. Policies that target socio-economic variables not included in our profit-focused framework (e.g., capital availability), area-based interventions (e.g., land zoning), or less-profit oriented actors (e.g., via community-based management) might be more effective in addressing deforestation rates in the Chaco.

1. Introduction

Humans have transformed the Earth for millennia by converting natural areas to agriculture (Foley et al., 2011). These conversions have resulted in a substantial increase in food production, but have also led to major trade-offs in terms of biodiversity, carbon emissions and diminishing non-provisioning ecosystem services (Gibbs et al., 2010; Newbold et al., 2015; West et al., 2010). Today, these trade-offs are especially apparent in tropical dry forest and savannas, which harbor high biodiversity and carbon stocks, yet are under intense land-conversion pressure (Aide et al., 2013; Kuemmerle et al., 2017; Laurance, Sayer, & Cassman, 2014; Portillo-Quintero, Sanchez-Azofeifa, Calvo-Alvarado, Quesada, & Do Espirito Santo, 2015). Understanding the underlying causes of land-use change in these regions, as well as the factors determining the spatial patterns of these changes, is therefore important to foster policy options that balance biodiversity and

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ecosystem services with agricultural production (Foley et al., 2005; Tilman, Balzer, Hill, & Befort, 2011).

The decisions of individual farmers, agricultural enterprises, and governments to expand or intensify agriculture are taken locally, but depend on a range of underlying causes operating across multiple scales (Angus, Burgess, Morris, & Lingard, 2009; Reidsma, Tekelenburg, Van Den Berg, & Alkemade, 2006). At the global scale, factors such as human population growth (Godfray, 2011; Hazell & Wood, 2008; Tscharntke et al., 2012), changing diets (Alexander et al., 2015; Bajzelj et al., 2014; Lambin & Meyfroidt, 2011; Tilman et al., 2011), as well as bioenergy production influence the demand for agricultural products and thus, international commodity prices (Geist et al., 2006; Lambin, Geist, & Lepers, 2003). At the regional scale, the level of technological development, political instability, or cultural ties to the land can play important roles in how land-use decisions are taken (Ceddia, Gunter, & Corriveau-Bourque, 2015; Gasparri & le Polain de Waroux, 2015; Thomas, Karl-Heinz, & Helmut, 2014). At even finer scales, a range of spatial determinants such as soil quality, climatic patterns, or socio-economic characteristics influence where agricultural expansion and intensification take place (Golub & Hertel, 2008; Lambin et al., 2013; Lubowski, Plantinga, & Stavins, 2008; Meyfroidt, 2015). To identify policies that can effectively influence land-use change toward desired outcomes, it is therefore essential to understand the relative importance of these factors and how they interact across scales to produce the spatial patterns of land-use change we observe (Levers et al., 2014; Meyfroidt, 2015).

Spatial Net Return Models (NRM) are powerful tools for that purpose as they are able to assess the combined impacts of underlying causes of land-use change, such as agricultural profitability, while controlling for spatial determinants influencing the configuration of land use (Bockstael, 1996; Butsic, Lewis, & Ludwig, 2011). The basic intuition of these models is that individual land owners maximize the utility from land use (Capozza & Helsley, 1989). In cases where land is used primarily as an input to production, which should be the case in regions where agricultural expansion takes place (Barbier, 2012; Le Polain De Waroux et al., 2018), utility can be proxied well by economic net returns (i.e., profit or loss). This theoretical concept can be translated to a statistical model via regression techniques (Wooldridge, 2011), allowing to model observed land-use change in terms of economic (including non-market) rents (Irwin & Bockstael, 2004; Lewis, Provencher, & Butsic, 2009). Yet, other factors than changes in marginal profit can have important influence on land-use decision-making. These include both economic factors, for example, land prices and speculation, capital availability, or macro-economic conditions, as well as non-economic factors, such as land tenure, cultural ties to the land by indigenous communities, traditional land uses, or corruption. (Arima, 2016; Ceddia et al., 2015; Dalla-Nora, De Aguiar, Lapola, & Woltjer, 2014; Dent, Edwards-Jones, & Mcgregor, 1995; Gasparri, Grau, & Gutiérrez Angonese, 2013; Henderson, Anand, & Bauch, 2013; Marinaro, Grau, Gasparri, Kuemmerle, & Baumann, 2017). The latter group of factors is particularly challenging to capture in an econometric modelling framework.

South America has recently been a global hotspot of agricultural expansion and intensification, triggering major losses in terms of biodiversity and no-provisioning ecosystem services (Aide et al., 2013; Laurance et al., 2014; Ramankutty, Foley, Norman, & Mcsweeney, 2002). Within South America, dry forests and grasslands are particularly prone to land-use change, especially in Brazil, Paraguay, Bolivia, Uruguay and Argentina (Graesser, Aide, Grau, & Ramankutty, 2015). The Pampas grasslands and Chaco dry forests of Argentina have experienced an especially high increase in agricultural production (Baldi & Paruelo, 2008; Gasparri & Grau, 2009; Grau, Gasparri, & Aide, 2005; Volante, Mosciaro, Gavier-Pizarro, & Paruelo, 2016), particularly of soybean since the 1990s, bolstering Argentina's role as a world-leading agricultural producer (Baumann et al., 2016a; Pengue, 2014). At the same time, this has triggered widespread loss and fragmentation of natural vegetation (Adamoli, Ginzburg, & Torrella, 2011; Aide et al., 2013; Piquer-Rodríguez et al., 2015; Torrella, Ginzburg, & Galetto, 2015; Viglizzo et al., 2010), and cropland is increasingly replacing grazing land in both, the Argentine Pampas and Chaco regions (Gavier-Pizarro et al., 2012; Lende, 2015).

Despite these rapid land-use changes, few studies have assessed the causes of agricultural expansion and intensification in Argentina, and these suffer from one or more of the following shortcomings. First, existing studies have focused only on spatial determinants such as soil quality or climate (Gasparri, Grau, & Sacchi, 2015; Volante et al., 2016), thereby neglecting the underlying causes of land-use change. These models can therefore not or only very indirectly assess the importance of profit-related factors on land-use change. Second, existing work has typically focused on small regions, typically inside a single ecoregion (Bert et al., 2011; Choumert & Phélinas, 2015; Zak, Cabido, Cáceres, & Díaz, 2008), thereby neglecting broad-scale patterns and potential connections between ecoregions and agricultural systems. Third, those studies that have assessed underlying causes have neglected the location factors determining land-use/cover change patterns (Bert et al., 2011), thereby disregarding the substantial spatial heterogeneity that exists inside these ecoregions. Finally, existing work has typically only studied forest loss (Gasparri et al., 2015; Volante et al., 2016), thereby potentially missing the interactions between agricultural expansion and intensification.

This translates into a substantial knowledge gap in our understanding of what causes land-system dynamics in one of the world's prime agricultural regions. To address this research gap, we developed a spatial net returns model of land-use/cover change for the years 2000 and 2010 in order to understand land-use dynamics in the Argentine Pampas and Chaco ecoregions. This decade had the highest agricultural expansion rates and agricultural production since the 1940s (Cáceres, 2015; Pengue, 2014). Our approach is, to the best of our knowledge, novel in that we (a) jointly model agricultural expansion and intensification, (b) assess both underlying causes (using cost and revenue data) and spatial determinants of land-use/cover dynamics, and (c) assess land-use/cover changes at fine resolutions (1 km^2), yet for multiple ecoregions simultaneously (in total 1,300,000 km^2). Specifically, we addressed two main research questions:

1. How did the underlying causes related to agricultural profitability affect land-use/cover change in the Pampas and Chaco regions between 2000 and 2010?
2. Which spatial determinants influenced agricultural land-use/cover change patterns in the Pampas and Chaco regions in that period?

2. Methods

2.1. Study area

Our study area encompassed the main agricultural regions of Argentina: the Pampas, the Espinal and the dry and humid Chaco ecoregions (~1.3 million km^2, Fig. 1). We included all districts that completely fell inside the ecoregions of the Pampas, Espinal, Dry Chaco and Humid Chaco (Olson et al., 2001) but excluded the very dry or mountainous districts in the southwest of the region (Conti et al., 2014). In Argentina, soy accounts for half the grain production and more than half of the cropped area in the country (Lende, 2015). Cattle ranching is also widespread with approximated 3 million tons of meat produced per year (www.minagri.gob.ar/ganaderia), of which 10% is exported (Santarcángelo & Fal, 2009). The Pampas has a longer land-use history than the Chaco, where cattle ranching started in the 16th century with the arrival of the first European settlers. Ranching shifted to cropping in many areas with the introduction and expansion of wheat, corn and sunflower in the 20th century, and the dramatic expansion of soybeans in 1990s displaced most ranching into the Espinal and the more isolated areas of the Chaco (González-Roglich, Swenson, Villarreal, Jobbágy, &