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Persistence of cattle ranching in the Brazilian Amazon: A spatial analysis of the rationale for beef production

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ABSTRACT

Fed by demand for beef within Brazil and in global markets, the Brazilian herd grew from 147 million head of cattle in 1990 to ≈200 million in 2007. Eighty-three percent of this expansion occurred in the Amazon and this trend is expected to continue as the industry bounces back from a recent agricultural downturn. Intensification of the cattle industry has been suggested as one way to reduce pressure on forest margins and spare land for soybean or sugarcane production, and is the cornerstone of Brazil's plan for mitigation of greenhouse gas emissions. To this end, federal credit programs and research and development activities in Brazil are aligning to support intensification goals, but there is no guarantee that this push for intensification will decrease the demand for land at the forest margin and as result curb CO_2 emissions from deforestation. In this paper we use a spatially explicit rent model which incorporates the local effects of biophysical characteristics, infrastructure, land prices, and distance to markets and slaughterhouses to calculate 30-year Net Present Values (NPVs) of extensive cattle ranching across the Brazilian Amazon. We use the model to ask where extensive ranching is profitable and how land acquisition affects profitability. We estimate that between 17% and 80% of land in the Amazon would have moderate to high NPVs when ranched extensively if it were settled, i.e. if the rancher does not buy the land but acquires it through land grabbing. In addition, we estimate that between 9% and 13% of land in the Amazon is vulnerable to speculation (i.e. areas with positive NPVs only if land is settled and not purchased), which suggests that land speculation is an important driver of extensive ranching profitability, and may continue to be in the future. These results suggest that pro-intensification policies such as credit provision for improved pasture management and investment in more intensive production systems must be accompanied by implementation and enforcement of policies that alter the incentives to clear forest for pasture, discourage land speculation, and increase accountability for land management practices if intensification of the cattle sector is to deter new deforestation and displace production from low-yield, extensive cattle production systems in frontier regions of the Brazilian Amazon.

Introduction

Brazil sits squarely under the magnifying glass of international scrutiny as both one of the largest CO_2 emitters from land use change, and the custodian of the largest tropical forest in the world. Recent efforts on the part of the Brazilian government to curb deforestation on private properties,[1] crack down on illegal logging (Serviço Florestal Brasileiro and Instituto do Homem e Meio Ambiente da Amazônia, 2010), encourage responsible land management on the part of cattle ranchers and soy farmers (Nepstad et al., 2009), and establish vast tracts of native forests as

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[1] In 1996, Brazil passed provisionary measure 1.511 to the Forest Code (Law 4.771, 1965) which changed the proportion of private property that must be maintained as a legal reserve from 50 to 80%. In May of 2011, the Brazilian congress passed a bill that lowered the proportion of legal reserve required in the Amazon back to 50%.

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protected areas (Soares-Filho et al., 2010)[2] when combined with the recent downturn of agricultural sector helped reduce deforestation in 2010 by 67% from the historical baseline of 19,600 km^2 per year between 1996 and 2005. Last year's optimism may have been unfounded; preliminary estimates from March and April of 2011 suggest that deforestation in the state of Mato Grosso from March and April of 2011 more than doubled when compared to the same period last year (BBC News, 2011; INPE, 2011). This may be due to some combination of uncertainty about the fate of the Brazilian Forest Code and the resurgence of agricultural commodity prices (OECD/FAO, 2011). Cattle ranching occupies more land than any other agricultural activity in the Brazilian Amazon (IBGE, census 2007) and will be a key component in designing policies for Brazil to achieve reductions in greenhouse gas (GHG) emissions from land-use and land-cover change.

The history of cattle ranching in the Brazilian Amazon can be traced to the early stages of European settlement. Cattle were bred as draft animals and were slaughtered for meat and leather to feed the growing domestic demand for meat and export demand for leather (Furtado, 1971). In the 1960s, colonization of the Amazon began in earnest. During this period, the government supported extensive ranching by subsidizing credit[3] and instating settlement and taxation policies that encouraged the establishment of *de facto* property rights through occupation and productive use (i.e. deforestation and cultivation) (Almeida and Uhl, 1995; Chaddad and Jank, 2006). Concomitant investments in road-building and infrastructure and the people that followed in their wake cleared large swaths of forest to lay claim to land and ranch cattle (Binswanger, 1991). There was much debate about whether expansion of extensive cattle ranching along the Amazon frontier in the 1970s and 1980s was either ecologically or economically sustainable without government incentives; many expected pasture land to be abandoned unless converted to more input-intensive types of production as soils became degraded (Fearnside, 1979, 1980; Hecht, 1985, 1993).

While these debates raged, growing demand for Brazilian beef in domestic and international markets fed growth in the industry during the 1990s. Population growth in urban centers in the Amazon such as Manaus and growth of per-capita consumption in the middle class have caused domestic demand for beef within Brazil to grow (Faminow, 1997a,b; Faminow, 1998; Aguiar and da Silva, 2002; Levy-Costa et al., 2005; Steiger, 2006). The signing of the MERCOSUL agreement between Brazil, Argentina, Uruguay, and Paraguay in 1991 also facilitated export of Brazilian beef within the southern cone (Polaquini et al., 2006). Global market conditions during the same period left Brazil in an ideal position to respond rapidly to the shift in demand for beef when the BSE (Bovine Spongiform Encephalopathy, or Mad Cow disease) crisis struck in the United States and Europe together with a drop in supply from Australia and Argentina (Faminow, 1998; Steiger, 2006). Beef exports grew from approximately 5% of production to 20% of production between 1990 and 2007 (Fig. 1), and this surge in demand for Brazilian beef for export meant that many regions demonstrated rapid improvements in sanitation and herd-management practices in order to control foot-and-mouth disease, as being certified free of foot-and-mouth disease (on a regional basis) was a pre-condition for export (Arima et al., 2005; Lima et al., 2005). The southern states of Rio Grande do Sul and Santa Catarina (which were free of foot-and-mouth disease with vaccination, and later without) met much of the early production for export, though exports from the Amazon states of Mato Grosso, Rondônia, Acre and Tocantins are on the rise in the last decade (Ribeiro et al., 2005; SECEX, 2000–2010).

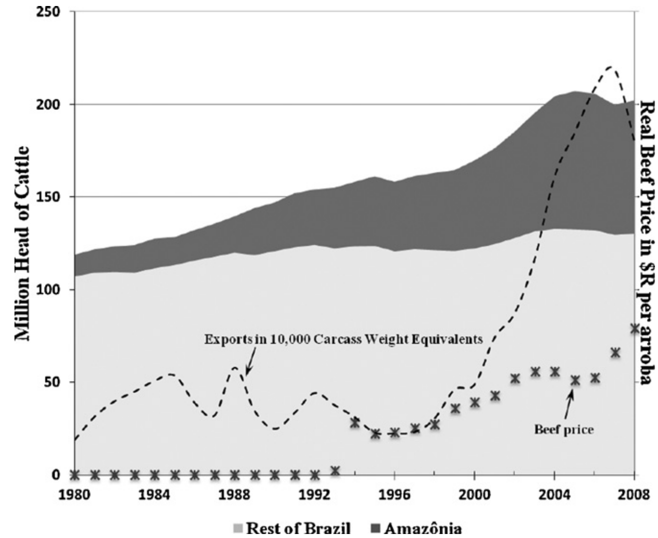

Fig. 1. Herd production trends in Brazil. This figure illustrates growth of the cattle herd in the Amazon and the rest of Brazil (stacked), real beef prices (1 arroba = 14.69 kg), and export trend (1980–2008). The total Brazilian herd expanded from 147 million to 200 million (36%) between 1990 and 2007. During this same period, the Amazonian herd has increased from 26 million to 70 million (an increase of 169%), and the herd in the rest of Brazil has increased from 121 million head to 130 million head (an increase of 7%). Data are publicly available from the IBGE *Produção da Pecuária Municipal* (herd size), the Foreign Agricultural Service of the U.S. Department of Agriculture (exports), and the Getulio Vargas Foundation (beef price), and the Carcass Weight Equivalent is the weight of meat cuts and meat products, converted to an equivalent weight of a dressed carcass.

The Brazilian herd grew from 147 million head of cattle in 1990 to 200 million in 2007 to become the world's largest commercial cattle herd (McAlpine et al., 2009). The majority of this expansion (83%) occurred in the Amazon (Fig. 1). The herd is clearly spreading westward and northward and is growing most rapidly in the states of Rondônia, Mato Grosso and Pará (Simon and Garagorry, 2005; Steiger, 2006). Today, cattle systems in the Amazon run the gamut from more traditionally extensive *cria-recria-engorda* (full-cycle production from calf to adult steers of slaughter weight) to cow/calf operations or fattening operations, as well as being an important component of both large-scale enterprises and small farm portfolios (Santos et al., 1999; Merry et al., 2004; Caviglia-Harris, 2005; Smeraldi and May, 2008). In spite of the prevalence of cattle ranching in the Amazon, many are puzzled by its spread given its supposed marginal profitability. Studies have suggested that profit and internal rates of return may be low or negative for many small-to-medium scale producers (Mattos and Uhl, 1994; Toniolo and Uhl, 1995; Merry et al., 2004), while larger ranchers may benefit from more significant economies of scale (Somwaru and Valdes, 2004). Barros et al. (2002) completed a comprehensive comparison of the economics of ranching in Pará, Mato Grosso and Rondônia, and found that internal rates of return varied from 9% (Redenção, PA) to 15% (e.g. Alta Floresta, MT and Paragominas, PA), and that profitability varied from 50 to 86 USD per hectare per year. Importantly, these studies do not address how capturing endogenous tenure security by clearing forest to ranch cattle

[2] In 2002, the Global Environment Facility provided 30 million dollars to establish the Amazon Region Protected Areas (PAs) project, or ARPA, which is administered by the Brazilian Ministry of the Environment (www.mma.gov.br). The project goal was to expand and consolidate the network of Amazon PAs. ARPA helped expand protected areas to account for approximately 46% of the total land area in the Brazilian Amazon.

[3] The Superintendent of Amazonian Development, or SUDAM, provided incentives for the establishment of large, extensive ranches in the region. By 1983, US 1 billion dollars (1982 dollars) had been invested by the government in these ranches and they covered more than 8 million hectares, with an average ranch size of 23,600 ha (Binswanger, 1991).

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or land speculation may contribute to the profitability of extensive ranching.

There is limited quantitative research that analyzes the contribution of land rent capture or demand for land in Brazil to the profitability of extensive ranching. Walker et al. (2008) and Jones and O'Neill (1994) provide a discussion of this process in the context of classical von Thünen location rent. Using a survey of more than 2000 households, Merry et al. (2008) study the determinants of estimated land values in smallholder households on the Transamazon, and Sills and Caviglia-Harris (2008) find distance to markets and property-level investments to be the most important variables affecting hedonic price estimates of land values in a frontier region of Rondônia. Cattaneo (2008) presents a simple theoretical model whereby the frontier actor captures increased land values of deforested land through the act of clearing land and establishing tenure. The von Thünen interpretation of the Brazilian reality is not altogether inconsistent with Boserup's (1965) description of the process of agricultural growth; agricultural intensification in Brazil along older frontiers and in the southern part of the country is likely driven by increased population pressure and, in turn, the increased demand for land for occupation and cultivation. Land quality and distance to markets are largely viewed as exogenous to the producer in the von Thünen tradition, but Boserup reminds us that agricultural productivity and soil fertility are dynamic and heavily influenced by population pressures and agricultural markets.

These hypotheses are borne out on older frontiers in the Brazilian Amazon where soy production is expanding; during the 2001–2004 period in Mato Grosso, more than 1/3 of the area where soybean plantings expanded was previously in pasture (Morton et al., 2006), and this increased demand for land plays an important role, both directly and indirectly, in driving the expansion of extensive ranching at the deforestation margin along with more intensive cultivation of soy and other crops on older frontiers (Morton et al., 2006; Cattaneo, 2008; Rivero et al., 2009; Barona et al., 2010). Thus, it seems plausible that positive rates of return to ranching in the Amazon may be due to ranchers' ability to capture increases in land value that accompany land clearing and tenure establishment, infrastructure improvements, and reductions in transportation costs, along with the rising trend in land prices due to increasing demand for agricultural commodities (Mertens et al., 2002; Margulis, 2004; Barreto et al., 2005; Steiger, 2006; Cattaneo, 2008).

Regardless of whether land markets and endogenous land tenure concerns underlie the profitability of extensive ranching, cattle ranching is clearly associated with deforestation. Pasturelands occupy approximately 85% of cleared areas (IBGE, 2007), and herd growth between 2000 and 2005 has a 40% correlation with deforestation (Soares-Filho et al., 2010). Between 60% and 80% of GHG emissions from land use change in Brazil are attributed to cattle ranching (Wassenaar et al., 2007; Garnett, 2009; Zaks et al., 2009; de Gouvello et al., 2010), and when combined with CO_2 and methane from livestock production[4] and growing of crops for livestock feed (Bustamante et al., 2009; Cederberg et al., 2011), cattle ranching is poised to become the largest source of GHG emissions from LULUCF (land use and land use change and forestry) if deforestation rates continue to slow.

It is this association between extensive ranching, Amazon deforestation, and environmental degradation that was the focus of an influential FAO report (Steinfeld et al., 2006a,b), a major media campaign by Greenpeace (2009), the World Bank Low Carbon Study (de Gouvello et al., 2010) and the Brazilian government response to pressure to develop a plan for the mitigation of greenhouse gas emissions (Comitê Interministerial Sobre Mudança do Clima, 2008; Embassy of Brazil, 2010). Cattle ranching's GHG footprint makes the activity central to the debate about how reductions in GHG emissions from land-use and land-use change are best achieved in Brazil (Cerri et al., 2010; de Gouvello et al., 2010; Galford et al., 2010; Cohn et al., 2011). Hence, Brazil's National Plan for Climate Change (PNMC) (President of the Republic of Brazil, 2008) and Brazil's proposed Nationally Appropriate Mitigation Actions (NAMAs) (Embassy of Brazil, 2010) focus on reducing emissions by constraining the land area occupied by extensive cattle ranching, and intensifying cattle ranching by adopting techniques that make pasture-based systems more productive on existing pasturelands (to a system considered to be semi-intensive or semi-extensive, rather than truly intensive) in order to dedicate more land to higher-yield activities such as crops for food or biofuel production. In doing so, all aforementioned plans argue that Brazil can reconcile forest conservation with crop expansion while reducing greenhouse gas emissions from ranching and yielding land to increased agricultural production as demand increases for food and biofuels produced in Brazil.

Whether intensification of the cattle herd will be accompanied by the reductions in deforestation necessary to make cattle ranching intensification a GHG-saving proposition is still not clear (Cohn et al., 2011). Although the media and international NGOs such as Greenpeace have pressured Brazil to crack down on cattle ranchers' deforestation by restricting market access for illegal producers, compliance with the terms negotiated as part of the cattle agreement initiated by Greenpeace has lagged[5] (Kaimowitz et al., 2004; Nepstad et al., 2006, 2009; Aliança da Terra, 2009; Greenpeace, 2009; Junior, 2009; Magalhães, 2009; Reuters, 2009; Vargas, 2009). Other policies and institutions have emerged to combat deforestation and encourage sound land management at the property level, including regional and federal property registries, land tenure reforms, and federal agricultural credit programs to finance improved low-carbon agriculture and land management (see http://www.agricultura.gov.br/desenvolvimento-sustentavel/programa-abc for a description of the low-carbon agriculture program, or ABC).

The idea of mapping and registering properties (including the area in forest and under production) was first a voluntary movement started by groups such as the Xingu Registry of Socio-Environmental Responsibility (Aliança da Terra, 2009), and later initiated at the federal level in the form of the Cadastro Ambiental Rural (CAR, or Rural Environmental Registry) in January of 2010 (President of the Republic of Brazil, 2009). Land tenure reform is also seen as an important tool to curb deforestation rates and improve land management in the region, and the Amazon Fund (http://www.fundoamazonia.gov.br) has allocated more than 1 billion dollars to enforcing deforestation, titling landholders and regularizing property rights. Even so, the relationship between deforestation and land tenure reform is not straightforward from either an economic or a policy perspective. There is much fear that both state-led and so-called "direct action" efforts to grant property rights may be perpetuating a system of perverse incentives for land grabbing and deforestation in anticipation of titling programs; a land tenure policy where claims to land are legalized ex-post will continue to incentivize deforestation unless major changes are made to titling programs (Economist Magazine, 2009; Caldas et al., 2010; Simmons et al., 2010). Furthermore, while

[4] In Brazil, emissions from the enteric digestion of livestock alone accounted for approximately 229 Mt CO_2e per year, or 18% of total greenhouse gas emissions in Brazil in 2008 (de Gouvello et al., 2010).

[5] As part of this agreement, major beef companies pledged to register and map all producers supplying beef directly to slaughterhouses by April, 2010 and by November, 2011 for indirect suppliers; the companies continue to lag in compliance (Greenpeace, 2010).

deforestation may be a way to gain land tenure, programs that grant tenure or title may also create economic incentives for producers to invest in more intensive property management since there is less risk of expropriation or of losing their landholdings, which could result in either increased or decreased property-level deforestation (Angelsen, 1999; Alston et al., 2000; Araujo et al., 2009, 2010). One study which evaluates the impacts of titling and land-reform programs on deforestation in Brazil after their implementation shows that the effects are heterogeneous and depend largely upon the previous land use (Pacheco, 2009).

Beyond merely monitoring property use and property-level deforestation, there is a vast body of growing research on more productive management systems that incorporate efficient pasture management, supplemental feeding, confinement, or integrated crop with livestock systems (Rueda et al., 2003; Cattaneo, 2008; de Gouvello et al., 2010; Euclides et al., 2010), and the federally funded EMBRAPA has developed a Best Ranching Practices program that outlines the major investments and technologies that landowners can employ to improve productivity and comply with environmental laws (Euclides Filho et al., 2002). In order to finance these transitions, federal agricultural credit programs have begun to emphasize funding for pasture improvements and other investments which may increase the productivity of ranching (Macedo, 2006; FNO, 2010), as well as to tie receipt of credit to environmental compliance. In practice, however, what we observe is growth in credit provision for rural commercial agriculture; rural agricultural credit for commercial agricultural enterprises grew from 15.6 to 107 billion Reais between 2000 and 2011 (Macedo, 2011) and in 2003, loans to cattle ranchers made up approximately 22% of rural credit (Macedo, 2006). The Northern Constitutional Finance Fund (FNO) established a new line of credit for ranchers in 2010 as part of the "Sustainable Amazon" line (FNO-Amazônia Sustentável) which provides 700 million Reais for capital and inputs to improve the productivity and sustainability of land use, but there appear to be few concrete monitoring provisions to ensure credit is being used for truly sustainable purposes.

To summarize, intensifying cattle production is envisioned as a means for Brazil to attain both reductions in enteric emissions and allow crop expansion without further deforestation (de Gouvello et al., 2010). Credit programs and research on cattle systems, together with the diverse set of policies described above, are aligning to support intensification goals, but there is no guarantee that a push for intensification stimulated by all these policies (which are still in their early stages) will decrease the demand for land at the forest margin, and as a result, curb GHG emissions from land-use change (Nicholson et al., 1995; Carpentier et al., 2000; Lambin et al., 2000; Hardie et al., 2004; Cattaneo, 2008). In fact, the literature suggests that some of the underlying drivers of extensive ranching in frontier regions of the Amazon—such as its role as a low-investment and effective way to lay claim to land or to capture the increases in land value associated with advancing infrastructure and land tenure—are key components not addressed by pro-intensification policies (e.g. Fearnside, 1979, 1980; Hecht, 1985, 1993; Jones and O'Neill, 1994; Walker et al., 2008). Therefore, understanding the drivers of extensive ranching is crucial to create an integrated policy landscape which supports intensification of the industry and deters deforestation on frontiers in the Amazon where extensive ranching is the predominant land use.

In order to map and quantify the rationale for extensive ranching in the Brazilian Amazon, we use a spatially explicit rent model which incorporates the local effects of biophysical characteristics, infrastructure, land prices, and distance to markets and slaughterhouses to calculate 30-year Net Present Values (NPVs) of extensive cattle ranching across the Brazilian Amazon. We use the model to ask where ranching is profitable and how land acquisition affects profitability, and then relate our results to recommendations for effective policies that target land titling without incentivizing deforestation, and penalize deforestation where land is not profitable. While previous work has used case studies or surveys to illustrate the relative profitability or lack thereof of extensive ranching in particular regions or used municipal-level statistics on pasture expansion and cattle herd size to analyze time trends, this paper is unique in two ways: firstly, it employs a spatial rent model based upon a detailed profit function that incorporates the local effects of biophysical characteristics, infrastructure, and distance to markets and to slaughterhouses to examine the returns to extensive, pasture-dependent ranching across the Brazilian Amazon, and secondly, it takes a first look at the contribution of the role of cattle ranching as a way to capture land tenure—an important driver not considered by previous studies in a quantitative way—to the profitability of extensive ranching across the Brazilian Amazon.

Data and methods

Model structure

The model is designed to simulate the 30-year Net Present Value (NPV) per hectare of extensive cattle ranching on a prototypical medium-to-large-sized farm (6000 ha of which we assume half are in pasture) for a given 4 km^2 unit cell area of the Brazilian Amazon. To arrive at this figure, we developed a spatially and temporally explicit profit function that reflects the fixed and variable costs associated with extensive cattle ranching in the region (Fig. 2). For a cell in year *i* with location *j*, we can express profit per hectare as:

$$\pi_{ij} = \alpha_j \left[\mathbf{P_j} \left(\frac{\mathbf{Q_{ij}}}{\boldsymbol{\omega}_\mathbf{i}} \right) - \boldsymbol{\omega}_\mathbf{i} \mathbf{C_{ij}} - \tau \left(\frac{\mathbf{P_j Q_{ij}}}{\boldsymbol{\omega}_\mathbf{i}} \right) - T_{ij} \left(\frac{\mathbf{Q_{ij}}}{\boldsymbol{\omega}_\mathbf{i}} \right) \right] - \mathbf{F_{ij}} \quad (1)$$

where α_j is the location-specific stocking density, $\mathbf{P_j}$ denotes output prices that vary by state, $\mathbf{Q_{ij}}$ is the volume of beef sold in a given year by output type, $\boldsymbol{\omega}_\mathbf{i}$ is a vector of herd proportions of each animal type being sold, $\mathbf{C_{ij}}$ are variable costs associated with production including input transportation costs from the nearest regional center, (urban centers of regional importance and state capitals (Garcia et al., 2007)), τ is the *ad valorem* tax rate on the value of animal sales, T_{ij} represents transportation costs of output to slaughterhouses, and $\mathbf{F_{ij}}$ represents the fixed costs specific to pixel *j* in year *i*.

Annual profit, π_{ij}, is calculated for each year that the model runs, and is then discounted to the initial year and summed over the 30 year time horizon of the model to arrive at a NPV figure (Eq. (2)) for a given cell, where δ is the intertemporal discount rate of 5%.

$$\mathrm{NPV}_j = \sum_{i=1}^{30} \frac{\pi_{ij}}{(1+\delta)^i} \quad (2)$$

We assume that, in the initial year, the agent acquires (either through purchase or occupation) and clears land, if it is forested. As a result of this, some clearing cost is incurred. If the land is forested, we simulate the sale of timber cleared during the clearing process—for this forest income, we use a simulated value of commercial wood volume determined by Merry et al. (2009). Income from timber sales, when included, ranges from $0 to $311 USD per hectare. This source of income for landowners is realistic, as much of the timber industry depends on logs from deforestation (Lima et al., 2006). Frontier landowners in the region sell timber during the deforestation process as a way to offset the costs of clearing land, as well as at other points in time to meet short-term capital constraints for various types of investment and agricultural intensification (Amacher et al., 2009). Following the process of land clearing, we assume that some upfront investment in property infrastructure is required (e.g. construction of

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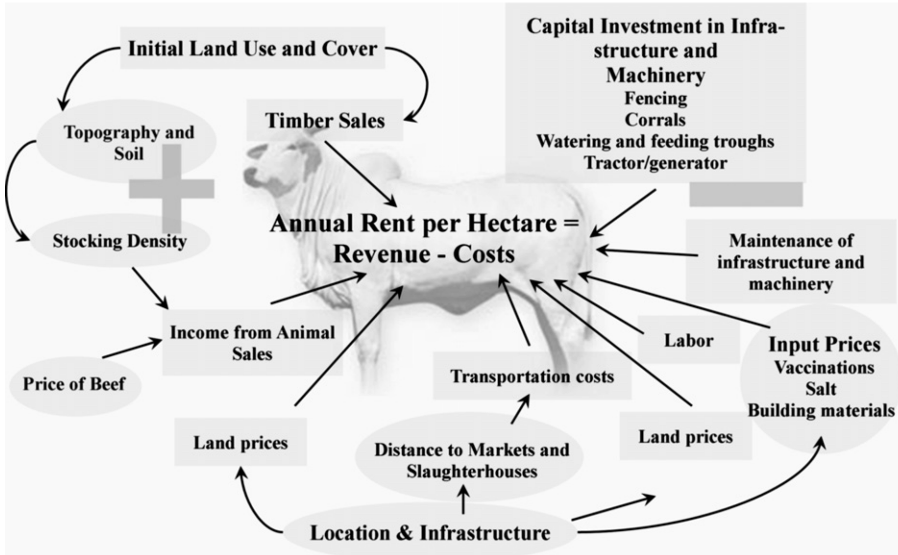

Fig. 2. Diagram of model interactions. Variables in our model that affect revenue are concentrated on the left hand side of the figure, and those that affect costs are on the right hand side. Sources of revenue include animal sales and land and infrastructure sales at the end of the 30 year period, and costs include transportation costs, input costs, land purchase, taxes, and infrastructure and maintenance costs. Feedback arrows give a simplified sense for the relationships between parameters and components of the model as depicted in Eq. (1).

fences and roads, a corral, water and feeding troughs). We estimate the value of these costs on a per-hectare basis by making reasonable assumptions about the level and type of investments made by a representative rancher with a 6000 ha property with 3000 ha of pasture (see Table 1 for a selection of parameter choices for the model). We use a combination of data sources for the costs and prices used in our model (Table 1), including state and region-specific prices gathered from a variety of government and non-government organizations and private enterprise during the 2006–2007 period, and data from a survey of 20 ranchers in the state of Mato Grosso.

We simulate the financial requirements of accessing formal credit markets to make upfront investments in ranching such as land clearing and road and fence building such that the rancher

Table 1
Summary of important parameter choices for the model, and sources used.

	Value	Sources
Interest Rate	8.75%	Constitutional Finance Funds administered by the Ministry of National Integration in conjunction with the Bank of Brazil, the Bank of Northeast Brazil, and the Bank of the Amazon
Discount rate	5%	
Exchange rate	2.0 Brazilian Reais: 1 US Dollar (2007 exchange rate)	http://www.federalreserve.gov
Rural property tax (ITR)	0.45% (for 6000 ha with 50% legal reserve and 80% utilization of area outside the legal reserve)	Receita Federal (http://www.receita.gov.br) Law 9.393 (1996) art. 11, and RITR/2002, art. 34
Federal sales taxes (INSS/SAT)	2.4% on value of sales	FAEMG/SENAG Notas Jurídicas ANO 1 – N◦ 16 (2006)
Land prices	Varied	FNP (http://fnp.com.br)
Property and capital investments, long-term maintenance rates	2–25% annually; fence maintenance is highest at 25% of installation cost; other infrastructure between 2 and 5%	Survey of Mato Grosso ranchers by Almeida et al. (unpublished data, 2006), Mattos and Uhl (1994), Barros et al. (2002) Santos et al. (1999), and EMBRAPA technical notes (various)
Transportation cost: inputs	Up to 100% of the input price; proportional to road distance to regional center	
Transportation cost: output	$.02 USD/km per adult animal equivalent on roads; off-road, costs increase from 1.5 times on-road cost to 3 times on-road cost at 20 km from the road. Actual transport costs are least-cost distance to SIF-registered slaughterhouse or regional center	Personal comm. (cost), slaughterhouse information obtained from the Federal Registry of Inspection (SIF) and Ministry of Agriculture via the website of Rural Business (https://www.ruralnetwork.com.br/)
Live animal and beef prices	State/region specific	Center for Advanced Studies in Applied Economics (CEPEA)
Mineral salt	$15.00–20.00 per 30 kg	Center for Advanced Studies in Applied Economics (CEPEA)
Vaccinations	$0.20–0.30/dose (brucellosis); $0.20–0.60/dose (carbuncolo); $0.50–0.70/dose (foot-and-mouth)	Center for Advanced Studies in Applied Economics (CEPEA)
Average stocking density	1 adult/ha	IBGE (2007), Faminow (1998), Barreto et al. (2005), and Barros et al. (2002)
Offtake	8.5% (steers as a percentage of total herd); 14.4% including female animals but excluding cows being culled	Santos et al. (1999), Barros et al. (2002), Rueda et al. (2003), and Merry et al. (2004)
Herd parameters	Calving rate: 60% Bull to cow ratio: 4% Animal survival rates: 80%, 96%, and 97% for years 1–3, respectively	
Labor	$190.00 per month (1 minimum wage) per ranch hand (5 per 6000 ha ranch) and double the minimum wage for one boss	Brazilian Ministry of Work and Employment (2006) http://www.mte.gov.br/

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repays on these loans during the first 12 years of the model using an annual loan repayment schedule specific to the interest rate and grace and repayment periods for different types of agricultural credit (Table 1). In addition, we incorporate maintenance for each type of infrastructure into annual (variable) costs. Similarly, we distribute the cost of purchase of a sufficient number of cows and bulls during the first several years of the model, and develop a simple population model that simulates the growth of a self-sustaining herd from these cows and bulls (see Merry et al., 2004). In each year, calves are born; female calves, mature steers, and a small percentage of cows (replacement) are sold; and a percentage of animals dies (Table 1). We assume a calving rate of 60% and a bull to cow ratio of 4%; animal survival rates are 80%, 96% and 97% for years 1 through 3, respectively; and offtake rates are 8.5% for steers (steers sold as a percentage of total herd) and 14.4% overall (including female animals being sold, but excluding aged cows being culled) (Santos et al., 1999; Barros et al., 2002; Rueda et al., 2003; Merry et al., 2004). These values determine $\boldsymbol{\omega}_1$ (Eq. (1)) and therefore influence input requirements and their associated costs, value of sales, and the *ad valorem* tax on animal sales. In the last year of the model, the rancher sells all assets.

Annual (variable) costs (Eq. (1) and Fig. 2) include infrastructure maintenance, taxes on the value of animal sales, and wages for a manager and 5 ranch hands. The largest portion of annual costs is comprised of the costs of vaccinating and maintaining the herd (see Fig. 2 and Table 1 for a decomposition of annual, variable costs). We incorporate the transportation costs for production inputs using a function that accumulates costs according to distances along paved and unpaved roads, and then differentially to distance for other land use cells. The input prices are then weighted by the transportation cost surface up to a maximum cost equal to n times the cost of the original input at the regional center. We use a value of 2 for n that accounts for most of the price surcharges in the far remote frontiers of the Amazon. The total cost of transporting animals from a given cell to a slaughterhouse location is the accumulated cost of transportation per animal as the animal travels to slaughter. For each kilometer traveled along the paved and unpaved road network, the cost is $.02 per animal, and outside of the road network the cost increases by between 50% and 200% per km, proportional with distance to the nearest road (Table 1). The spatial database for current and planned paved highways and detailed network of vicinal roads comes from Soares-Filho et al. (2006). Initial location-specific stocking density varies slightly from 0.9 to 1.1 as a function of soil and climatic conditions. Annual profit (Eq. (1) and Fig. 2) is comprised sales of each type of animal—steers are assumed to be sold at a slaughter market weight of 175 kg (at a 40–50% cutout that is the equivalent of approximately 435 kg live weight) at a state-specific price. State prices vary considerably, primarily due to the suitability or lack thereof of beef for export, which requires that a state be foot-and-mouth disease-free. The beef price in Mato Grosso was 16% higher than the average beef price in the region in 2007. Additional animal sales that contribute to annual profit are sales of female calves that are not retained for replacement for breeding purposes, as well as aging cows that are culled.

Scenarios modeling

We focus on a key factor that underpins the overall profitability of ranching in the Brazilian Amazon as well as its spatial variation: the role of land settlement and tenure acquisition. As such, we develop two scenarios designed to assess the role of land tenure acquisition in ranching profitability and its expansion and to examine the implications for the future of policies in the Brazilian Amazon that aim to deter deforestation on the frontier and to achieve GHG emissions reductions through the intensification of cattle ranching. These scenarios help demonstrate the historical rationale of cattle ranching as a means to ensure land tenure in the Amazon, and suggest ranching prevails at the frontier because it continues to be a way to lay claim to cheap land and establish tenure. In order to consider the impact of different variable input and output price trajectories on ranching profitability, we also perform sensitivity analysis for each scenario by varying output-to-input price ratios (15% lower and 15% higher price ratios than those of 2006/2007). The two scenarios can be described as follows:

Land purchase or "buys land"

Here, we assume that the rancher acquires land at current prices (FNP, 2007), and must borrow to do so. The rancher repays on principle and interest over a 9 year period after a 3-year grace period. At the end of the 30-year period, the rancher sells his land for the original amount he paid for it. The idea is that this scenario represents the case in which there is no land speculation or advantage to holding onto a parcel of land through cattle ranching.

Land speculation or "settles land"

This scenario considers the case in which the rancher acquires the land at no cost, but is able to sell the land at the price he would have paid had he purchased the land at the end of 30 years. This scenario reflects a story of (successful) speculative behavior of Amazon land grabbers or squatters (Alston et al., 1996, 2000; Faminow, 1998; Margulis, 2004; Araujo et al., 2009); the rancher clears the land and makes it productive, and captures the value of the land and endogenous tenure rights through settlement and cultivation.

We designed and ran our models using Dinamica EGO freeware (Soares-Filho et al., 2009). For each scenario, we looked at how Net Present Values (NPVs) and total profitable area in the Amazon vary according to whether the rancher buys or settles land (Fig. 3 and Table 2), and how profitability varies by region (Fig. 4). In addition, we used the difference in NPVs between the two scenarios to identify land that is profitable (NPV per hectare > $0) in the case where the rancher settles the land, but is not profitable if the rancher must buy the land. We present the results for the modeled scenarios in Section 3.

Results

Land purchase scenario

In this scenario, we assume that the rancher acquires land at current prices (FNP, 2007), and must borrow to do so. As a result, this scenario exhibits the lowest Net Present Value estimates, which is as expected. 30-year average Net Present Value estimates range from $-172 to $39 USD per hectare on forested land and from $-156 to $58 USD per hectare on deforested land for this scenario. The distribution of deforested and forested area according to NPV can be seen in panels (A) and (B) of Fig. 3 for deforested and forested area, respectively. Output-to-input price ratios make a significant difference in threshold profitability for forested land (Fig. 3B). For the lower output-to-input price ratio 14.9% of all land has a positive 30-year NPV, but only 2.3% has moderate to high NPV (greater than 250 USD). For the higher output-to-input price ratio, 82% of land has a positive NPV, and 50% has a moderate to high NPV (Table 2). States with regions with high land prices (e.g. Mato Grosso, Tocantins, Pará, and Rondônia) exhibit much greater variability in profitability under this scenario (Fig. 4).

Taking a close look at panels C and D of Fig. 4, we show that, in general, the areas where land prices have skyrocketed as a result of soybean cultivation (western and eastern Mato Grosso) show a negative NPV for cattle ranching if the rancher must buy the land. Just outside the regions where soy has taken hold in western Mato Grosso and along the BR-163 (Cuiabá-Santarém highway), we find that land prices and transportation costs are low enough that

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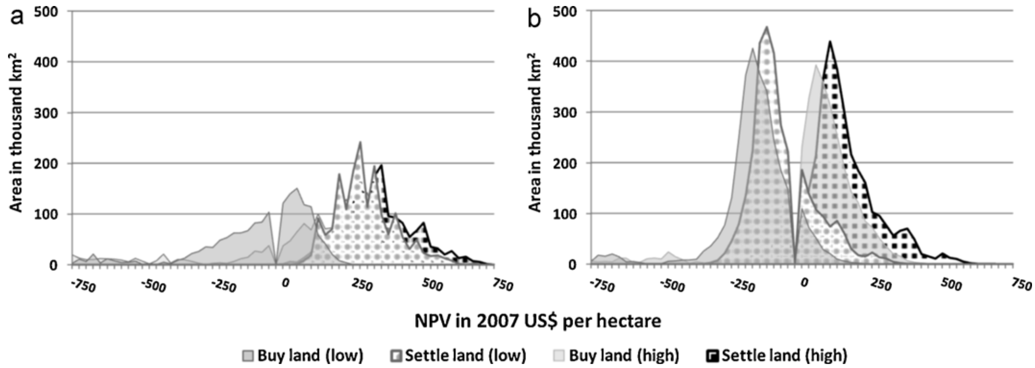

Fig. 3. Land area histograms of 30-year NPV ranges on already-deforested land (A) and forested land (B) for high and low ranges of the scenarios where the rancher buys land and settles land.

ranching has strongly positive NPVs. Expected NPV is positive if a rancher clears land in northwestern Mato Grosso, and through much of Rondônia, as well as in the areas surrounding Rio Branco and Manaus and the deforestation margin along most major roads. Table 2 shows, however, that the percent of land with a positive NPV varies greatly for this scenario when we compare high and low output-to-input ratios. Areas that have a positive NPV under the low output-to-input price ratio run of this scenario (see Fig. 4D) are likely to be those that are most vulnerable to deforestation for extensive ranching under any market conditions. These areas, where, in general, markets are close and land prices are still low to moderate, are concentrated along the BR-163 (Cuiabá-Santarém highway) in the western part of Mato Grosso (around Sinop, to the east of Sinop and northwest of Sinop), along the BR-364 in Rondônia around Porto Velho, and in the periphery of Manaus.

Land speculation scenario

This scenario simulates a situation where ranchers are acquiring land at no cost and capturing the value of the land by settling and establishing land tenure. Not surprisingly, this scenario does the best job at explaining actual patterns of expansion of extensive ranching in the Amazon (e.g. Rivero et al., 2009). Most frontier areas exhibit positive Net Present Values with high output-to-input price ratios (100% of deforested and 98% of forested land), though only 79% of areas have moderate to high NPVs (see Table 2 and Figs. 3 and 4). With low output-to-input prices, settled land is profitable in only 40% of the Amazon, with only 17% being of moderate to high profitability. Average NPVs on deforested land range from 116 USD/ha in Amapá to 390 USD/ha in Mato Grosso and on forested land, from 54 USD/ha to 300 USD/ha (Fig. 3). The highest Net Present Values are in the cerrado of Mato Grosso, Tocantins, Rondônia, and around Rio Branco (AC), Manaus(AM), and Santarém (PA), and along the deforestation margin of already-established corridors such as the Belém-Brasilia highway (BR-10/BR-153) and the Porto Velho-Cuiabá highway (BR-364) (Fig. 4). Regions exhibiting negative Net Present Values are only those that are completely inaccessible (e.g. remote regions of Amazonas and Pará).

General results

When we consider the regional and spatial distribution of NPVs in each scenario, we see that higher output-to-input price ratios are important shifters of the distribution of NPVs (Fig. 3), and that average Net Present Values are highest in Mato Grosso and Tocantins, and lowest in Amazonas and Para (Fig. 4). All else equal, NPVs are higher on already deforested land when compared to forested land due to the clearing costs associated with converting forested land. Because deforested land is more likely to be close to roads, however, it is also more likely to have both lower transport costs associated with it and higher land values, and these two variables seem to have opposing effects on profitability in the scenario where the rancher buys land.

If we take a static snapshot of annual rent (profit in year 20, for example), our estimates fall within the range of existing estimates in the literature (annual profit estimates from our model if we ignore fixed costs such as purchasing animals and tractors are roughly 12–80 USD/ha), and support previous research that has found that ranching, if we ignore land investment or opportunity costs, is profitable, though only marginally so (Mattos and Uhl, 1994; Barros et al., 2002; Rueda et al., 2003). For the case of true frontier regions in the Amazon, our results may over-estimate rancher investments in their properties as well as animal health care. In addition, many ranchers supply beef to clandestine slaughterhouses thereby avoiding taxes we incorporate in our model. Thus, for these regions, we acknowledge that our NPV estimates

Table 2
Total Net Present Value and percent profitable area for model scenarios. The column labeled "low price" is for output-to-input price ratios that are 15% lower than 2007 output-to-input price ratios, while the column labeled "high price" is for those that are 15% higher.

			Low price	High price
Buys land	NPV > $0	Total NPV	$22,263,559	$122,185,265
		Percent of land area	14.9%	81.5%
	NPV > $250	Total NPV	$3,413,580	$74,477,239
		Percent of land area	2.3%	49.7%
Settles land	NPV > $0	Total NPV	$59,597,089	$146,622,559
		Percent of land area	39.8%	97.8%
	NPV > $250	Total NPV	$25,349,957	$118,529,403
		Percent of land area	16.9%	79.1%
Speculation Frontier[a]		Total NPV	$13,911,420	$19,786,270
		Percent of land area	9.3%	13.2%

[a] Negative NPV/ha if rancher buys and positive NPV/ha if rancher settles (NPV > $0).

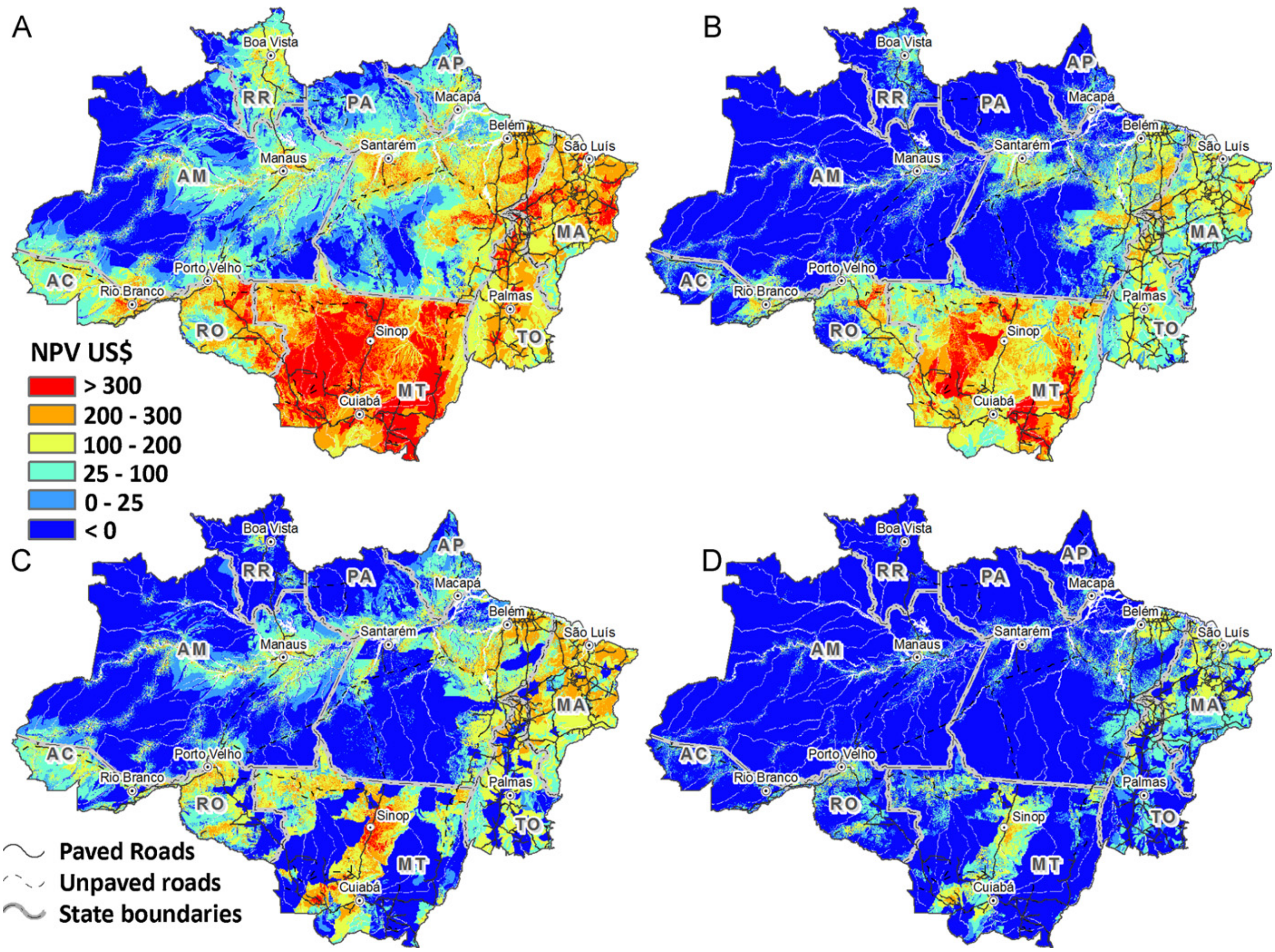

Fig. 4. (A)–(D). NPV ranges in $USD/ha for land in the Brazilian Amazon for the Land Speculation (A and B) and Land Purchase (C and D) scenarios. Maps A and C are for 2007 output-to-input price ratios, while B and D show NPV for output-to-input price ratios that are 15% lower.

may be a lower bound for large ranches. Implicit in our parameter choices, however, are significant economies of scale with respect to fixed costs, and so we may be overestimating NPVs for smaller producers.

Identifying areas vulnerable to land speculation

Using the results from our two scenarios, we are able to identify land that is profitable (NPV per hectare of >$0) in the case where the rancher settles the land, but is not profitable if the rancher must buy the land. We consider these areas to be prone to land speculation (Fig. 5). They are areas where we would expect extensive ranching to be growing, and in turn are areas that should be targeted as current or future critical regions for enforcement of forest and environmental laws. In this respect, the model accurately pinpoints the contested frontiers along BR-163 (a), Transamazon highway (b), and Terra do Meio (c) in the state of Pará, Apuí (d) and Boca do Acre (e) in the state of Amazonas and south of Boa Vista (f) in the state of Roraima (Fig. 5). We provide further interpretation of these results in the Discussion and conclusions.

Discussion and conclusions

The degree to which extensive ranching is profitable and where can depend a great deal upon the set of assumptions with respect to the process of land acquisition, as well as expectations about price trajectories. Our results show that land grabbing at the frontier with the expectation that infrastructure, markets, and more productive agricultural commodities will advance with time contributes to the persistence of extensive ranching in regions where it is only marginally profitable to raise cattle, even as technology and input-availability improve. Our results also support other studies that suggest that vast regions of the Amazon are marginally profitable for extensive production of beef and therefore have a low agricultural opportunity cost of avoiding forest conversion to pasture (Chomitz and Thomas, 2003; Nepstad et al., 2009); the total potential Net Present Value of cattle ranching in areas identified as vulnerable to speculation in Fig. 5 is estimated to be between 14 and 20 million dollars (Table 2). Hence, these areas are more prone to the expansion of extensive ranching due to land speculation—areas that are or may well be subject to increasing deforestation rates—and should be targeted for the enforcement of forest laws and for titling and land tenure reform.

Moreover, our results also suggest several things that are relevant to the intensification debate. Firstly, because they show that large regions of the Amazon are only marginally profitable for ranching, they imply that the producer-level incentives for capitalization or intensification in such regions may be a sticking point because it may be costly for ranchers to adopt more intensive technologies, and there is uncertainty about whether such technologies will be profitable in these regions. In the future, we hope to adapt

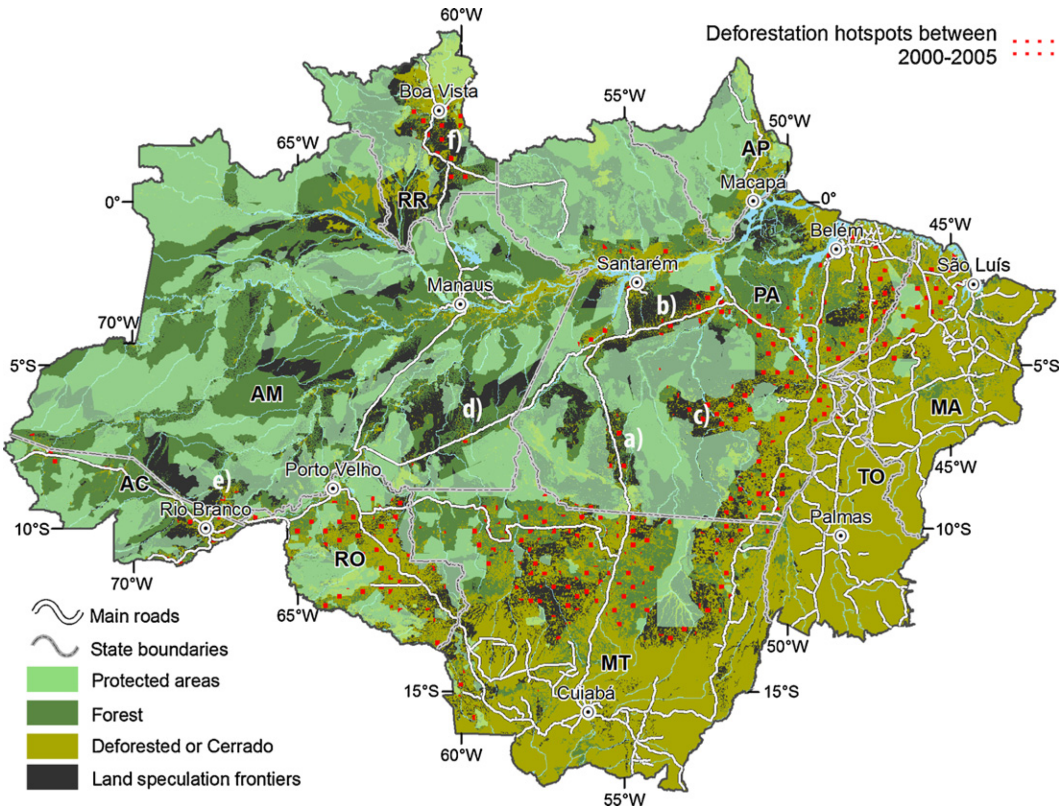

Fig. 5. Areas prone to land speculation, i.e. areas where it is profitable (NPV > $0) to settle the land and ranch cattle but not profitable (NPV < $0) if the rancher must buy the land.

our model and use it as a tool to identify areas which should be prioritized for cattle ranching intensification due to high output and profitability if Brazil were able to target producer incentives to adopt more intensive production types on a regional basis. To assess investments needed to set such policies in motion, the model also could be adapted to calculate regional costs and returns of intensive cattle raising systems.

Large swaths of the Amazon may be only marginally profitable if ranched extensively, but they are still profitable, particularly when we consider land speculation. The results of our analysis suggest that, even if intensification were economically viable for ranchers in some regions of the Brazilian Amazon, investments in semi-intensive production and improved productivity in the cattle herd of the Brazilian Amazon must be combined with investment in policies and institutions whose primary intent is to discourage extensive ranching and curb deforestation if they are to reduce pressure on forests and spare land for more productive uses (Angelsen, 2010; Martinelli et al., 2010; Sparovek et al., 2010).

With such policies in place, it may be possible to control deforestation at the extensive margin. Producers will begin to intensify only when the marginal return to cutting forest and ranching extensively is lower than that of intensifying (e.g. Kaimowitz and Angelsen, 1998; Cattaneo, 2008), and as Kaimowitz and Angelsen (2008) point out, it is possible that if intensification proves profitable, it will *increase* rather than decrease the demand for land for cattle production in Brazil without complementary policies to curb new deforestation or expansion. Therefore, if Brazil wants to nudge the cattle industry toward intensification and decrease new clearing of forest for ranching, it will need to combine reform of longstanding policies that encourage the clearing and utilization of land to establish land tenure with policies that promote environmentally and economically sustainable semi-intensive production models while also constraining the amount of land available for expansion of cattle production.

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