Exchange Rates, Soybean Supply Response, and Deforestation in South America

By Peter D. Richards

A PLAN B RESEARCH PAPER
Submitted to

Michigan State University
in partial fulfillment of the requirements
for the degree of
Master of Science

Department of Agricultural, Food, and Resource Economics
October 2012

Abstract

The advancement of South America's agro-pastoral frontier has been widely linked to losses in biodiversity and tropical forests, with particular impacts on the Brazilian cerrado, the Atlantic Forest, and the Amazon. Here I consider an important, yet largely overlooked, driver of South America's soybean expansion, namely the devaluation of local currencies against the US dollar in the late 1990s and early 2000s. Much interest has emerged in recent years over the environmental implications of soybean production in Brazil, with evidence of both direct incursions into moist tropical forest by soybean producers and of potential indirect effects, via the displacement of existing ranching operations. In this research I utilize historical trends in soybean prices, exchange rates, and cropland dedicated to soybean production in Bolivia, Paraguay, and Brazil to estimate the impact of currency devaluations on area of production. The results suggest that approximately 80,000km², or 31 percent of the current extent of soybean production in these countries, emerged as a supply area response to the devaluation of local currencies in the late 1990s. The results also indicate that the more recent depreciation of the dollar and appreciation of the Brazilian real have counteracted a recent rise in global soybean prices, in the process sparing an estimated nearly 90,000 km² from new cropland, 40,000 km² of this in the Amazon alone.

Acknowledgements

This work was possible thanks to the members of the graduate committee responsible for this work and the quality of the faculty and graduate students at AFRE. I would like to recognize, in particular, the patience and assistance of principal advisor, Dr. Scott Swinton, who graciously took me on as one of his students and persevered with me in my pursuit of this degree; of Dr. Robert Myers, who, with a skillfully placed comment, could illuminate for me the concepts and methods that would become critical to this paper; and Dr. Robert Walker, who led me to my work in Brazil, and who inspired me with his broad perspectives on the Amazon, life, and academia. Their combined interest in my work, and their diligence in seeing me through to its completion, have greatly improved the quality of this paper and were formative influences on my academic development.

Table of Contents

Exchange Rates, Soybean Supply Response, and Deforestation in South America[1]

1. Introduction and background

The disappearance of the world's tropical forests has been widely linked to losses of biodiversity and the unhinging of global climate balances(Turner et al., 2007). A great deal of concern in this regard has focused on the South American continent, where the Atlantic Rainforest has largely disappeared, and where the Amazon forest has suffered high rates of deforestation loss for nearly four decades. A large amount of research has addressed these land cover changes and implicated a wide array of drivers in the process; however, there is little doubt that agricultural expansion has played a key role in forest loss across South America (DeFries et al., 2010, Andersen et al., 2002, Kaimowitz and Smith, 2001, Lambin and Meyfroidt, 2010). Much of the recent deforestation in South America appears to be closely connected to the expansion of crops and cattle for export markets.

The present paper focuses on a major component of agricultural expansion in the South American continent, namely the soybean boom of the past few decades, which has turned Brazil into a leading exporter, and Paraguay and Bolivia into significant players in the global marketplace. Evidence has already pointed to the environmental impacts of soybean agriculture in this region, both as a direct driver of forest loss and as an indirect driver, via indirect land use change, particularly with the displacement of cattle production to forest frontiers (Lapola et al., 2010, Walker et al., 2009a, Arima et al., 2011, Morton et al., 2006, Barona et al., 2010, Brandão et al., 2006, Brown et al., 2005). In this analysis I take the broad-scale ecological consequences

[1] A previous version of this paper was published in *Global Environmental Change*, as:
Richards, P.D.; Myers, R.J.; Swinton, S.M.; Walker, R.T. 2012. Exchange rates, soybean supply response, and deforestation in South America. *Global Environmental Change* 22 (2) 454-462.

of agricultural expansion in lowland South America as given, and turn attention to the acceleration of agricultural growth in this region since the late 1990s.

Although the early emergence of the South American soybean industry has regularly been linked to the upward spike in global prices for protein meals in the 1970s (Warnken, 1999), more recent research on the evolution of agricultural frontiers in Brazil, Paraguay and Bolivia has largely concentrated on changes from the supply side, or the internal development of agricultural and social policy and infrastructure projects. The expansion of South American agriculture has thus already been widely linked to domestic initiatives concerned with territorial expansion and national security, the construction of roads into the Atlantic and Amazon forests, the development of ports and waterways, or the use of financial or migration incentives to simultaneously lure human and financial capital and to decrease transaction costs (Hecht and Mann, 2008, Rudel et al., 2009, Walker et al., 2009b, Brannstrom et al., 2007, Jepson, 2006, Jepson et al., 2010, Pfaff, 1999).

More recently, however, growth in soybean production in South America has also been tied to a growth in global demand for the product and new access to regions, such as South America's interior, which, through infrastructure developments and the relocation of essential farming skills and capital, have only recently incorporated into global networks of food consumption and production (Lambin and Meyfroidt, 2011, Naylor et al., 2007, Naylor et al., 2005, Tilman et al., 2002). Today, as market reforms and neoliberal economic policies have taken hold across Latin America, consumers in distant nations are increasingly able to access the region's natural resources and employ its bountiful reserves of agricultural land for the production of food commodities. In the present text I build on these demand side considerations of global food production and market dynamics. In the process I bring to light an important but often overlooked driver of deforestation, namely the role of currency exchanges in determining the location and extent of agricultural production.

In this paper I suggest that currency fluctuations were responsible for a significant portion of new soybean production in South America since 1995. The results indicate that nearly 80,000km² of soybean production in Brazil, Bolivia, and Paraguay, thirty-one percent of the current area of soybean production in these countries, may be attributed to the devaluation of their currencies in the mid 1990s. I further suggest that the recent appreciation of the Brazilian real has offset rising global prices for food, thus mitigating the effect of a late surge in soybean market prices on local production incentives and sparing more than 85,000km² of land from crop expansion. Of this,40,000km² was in the Amazon alone. These findings reinforce the notion that currency dynamics are a significant determinant of the international spatial distribution of agricultural growth, and offer the implicit suggestion that they also are integral in distributing the global degradation of environmental services. As nations and regions become increasingly connected within an international web of trade, the relative impacts of currency appreciation or devaluation on the extent of agricultural production will only be further heightened. As will be shown in the upcoming sections, few industries are likely to be as responsive to major currency fluctuations as the soybean industry.

2. The Soybean Boom in South America, 1999-2003

In the 1990s a series of structural reforms in Brazil and elsewhere removed many of the policy obstacles that restricted international access to South American agricultural commodities. Reductions in tariffs and export taxes, the stabilization of the Paraguayan guaraní and the introduction of the Brazilian real, and the establishment of the Common Market of the Southern

Cone (MERCOSUR), for example, eased many of the traditional barriers to agricultural exports in the southern cone (Helfand and Rezende, 2004, Hecht and Mann, 2008). Internally, the fulfillment of the transformation from military to democratic governments in Brazil and Paraguay and a trend of market liberalization shifted private investments towards the production of export commodities. In Brazil, price support policies and the regulation of principal commodities such as coffee, sugar, and rice, once seen as critical to national security, likewise were slowly dismantled and subjected to market demand. In Paraguay, the opening of the Atlantic Forest frontier and its settlement by Brazilian agricultural colonists resulted in the cultivation of an emergent soybean sector (Richards, 2011a). Cumulatively, the whole of these reformations in agricultural and trade policy eased access for importers and opened new markets to the region's farmers. With the removal of obstacles to trade, the region was poised to respond to a favorable market shift. Ultimately, the market shift that emerged came not through a surge in international prices for agricultural goods, but a favorable shift in the exchange rate with the US dollar.

In the mid 1990s the United States, through emerging from the recession of the earlier part of that decade, incrementally increased its federal funds rate from three to six percent, a tactic designed to ward against possible inflation (figure 1). The stronger dollar indeed emerged, but it was delivered with a series of secondary repercussions that affected many distant economies. The higher valued dollar contributed to the fall of foreign currencies and led to economic turmoil abroad, first in East Asia, but also later in South America (Baig and Goldfajn, 1999, Corsetti et al., 1999). Brazil was forced to float its currency in 1999. Argentina followed at the end of 2001, and then watched its peso plunge to historic lows, its presidents deposed and, ultimately, a default on portions of its insurmountable national debt. Paraguay's guarani, already free floating, fell to less than one-third of its 1995 value. The devaluation of domestic currencies, however, would prove to be a double edged sword, for even as the economic fallout challenged the foundations of the South American economies, it also heightened incentives for farmers to increase their output of internationally traded commodities. From 1996-2002, as global prices for soybeans were stable in US dollars, in Brazilian reales, Paraguayan guaranies and Bolivian bolivianos, prices were approaching historical heights. Hence at the same time that US producers were suffering from a decline in real prices for soybeans, South American farmers were reaping windfall profits. With such a favorable economic outlook and with high rates of return on soybean production capturing more investment capital for the industry in South America, producers rapidly expanded with investment capital from sources both domestic and international.

Although much of the growth in Brazilian exports during the late 1990s and early 2000s was directed towards Europe, more recently it the growth of Chinese demand that has sustained prices despite the rapid increase in production. The Chinese yuan remained pegged to the US dollar between 1995 and 2005, which allowed Chinese consumers to benefit from the strong dollar and comparatively weak currencies of their South American exporters. For at the same time that soybean prices were falling in US dollars and Chinese yuan, South American farmers were reaping ever higher prices for the commodity. From 1996 to 2008 Brazilian soybean exports to the EU tripled from 2.9 million tons to 8.9 million, peaking at 10.7 million in 2005. However, during the same period, Chinese soybean imports grew eight-fold, rising from 0.15 million tons in 1996 to 12 million tons in 2008, by then accounting for 49 percent of the 24 million tons of soybeans exported from Brazil that year (Food and Agriculture Organization, 2011b). Assuming continued growth in Chinese consumption, Brazilian soybean exports to China are forecasted to continue to rise (Masuda and Goldsmith, 2009).

The vast majority of South American soybeans are destined for international consumption, a fact which separates soybeans from many other principal food export commodities of South America. For example, while Brazil exports approximately nineteen percent of its beef production abroad (Foreign Agricultural Service, 2010), for soybeans, Brazil's most important agricultural export, approximately seventy percent of the total weight of its soybean harvests is sent abroad for foreign consumption.[2] The heavy reliance of Brazil's soybean production on international demand heightens its sensitivity to the dynamics of the international marketplace.

3.1 Exchange Rates and Agricultural Production

Because many agricultural products are traded in US dollars, a favorable price for producers of these traded commodities depends not only on the market price of the commodity, but on the exchange rate of the domestic currency against the dollar. An exchange rate is thus an important mediating mechanism between global markets and local production decisions (Schuh, 1974, Chambers, 1988). Just as with changes in commodity prices, fluctuations in the exchange rate will not only decrease or increase agricultural export demand, but will also influence agriculturally based incomes and land values (Hooper and Kohlhagen, 1978). Appreciation of an exporter's currency is tantamount to a decrease in product price for local producers. Depreciation results in the opposite, a rise in local prices for the good. Hence, currency depreciation results in increased incentives for producers to expand production of export goods

[2] Total export weight includes unprocessed soybeans, soy oil, and soy meal. Soybeans contain roughly 17.8% oil, 79% meal, and about 3% waste. .

(Chambers, 1981, Houck, 1986). Given that currency values are necessarily relational, production decisions at the farm level can therefore be linked not only to the dynamic economic conditions of the exporting and importing nation, but in the case of multiple exporters, also to those in competing exporting nations (Schuh, 1976). Naturally, the degree to which a change in the exchange rate results in an increase or decrease in demand for a good also depends on the elasticity of demand and supply for the product (Kost, 1976).

The USDA's Economic Research Service estimates that the exchange rate accounts for a significant portion of changes in US agricultural profits (Economic Research Services, 2001). When in the early 1970s US agricultural exports declined, despite the use of production subsidies to promote their production, a strong dollar relative to potential importers' currencies was ultimately identified as a cause (Longmire and Morey, 1983, Schuh, 1974). As the world's commodity networks have become increasingly integrated, evidence of the exchange rate acting as a determinant of the expansion or contraction of agricultural exports continues to be compiled. During the most recent period of appreciation of the US dollar (1995-1999), the value of US agricultural exports declined from sixty to forty-nine billion US dollars (Economic Research Services, 2001). In Argentina, the controlled undervaluation of the peso stimulated agricultural profits and production in the 1970s and 1980s (Grigsby and Arnade, 1986). And in North America, the devaluation of the Canadian dollar was tied to an increase in US feed cattle imports for slaughter (Mattson et al., 2001, Anderson et al., 1989).

In recent years, it has also been pointed out that growth in natural resource exports may wield the often unintended effect of currency appreciation and, ultimately, unfavorable economic conditions for the manufacturing of goods destined for export markets. This phenomenon is also known as "Dutch Disease," after economists perceived that growth in natural gas exports triggered an appreciation of the guilder in the 1960s, which ultimately adversely affected sectors of the Dutch economy (Corden, 1984). The impacts of currency appreciation associated with export growth and their relationship to the region's broader economy have also been examined within the Amazon (Wunder, 2000, Barnham and Coomes, 1994) .

The devaluation of a domestic currency will affect soybean producers' profits both positively, through the value of the output product and negatively, via rising costs for traded inputs. As will be shown in the following section, the devaluation of the local currency will increase the value of the traded commodity in local prices. However, it may also increase the costs of any inputs that may need to be imported. In the case of commodities such as soybean or corn, which rely heavily on imported stocks of fertilizer and in some cases, imported machinery, purchasing costs for these goods may rise. That inputs are often purchased months in advance of harvests can complicate profit calculations, given that the exchange rate may change between planting and harvesting. In any case, as the value of crops produced is generally expected to exceed the value of the required inputs, the net effect of a devaluated currency is likely to be positive.

While the impact of currency fluctuations has drawn the attention of international economists, little or no work has linked exchange rate fluctuations to changes in the geographical location of agricultural production, despite the obvious linkages between these changes and losses in environmental services. With few exceptions, (Arcand et al., 2008), references to the role of currency fluctuations in land change science literature, if present, are largely anecdotal (Nepstad et al., 2006, Walker et al., 2009a, Brandão et al., 2005) or inconclusive (Ewers et al., 2008). This paper clarifies the mechanics underlying the exchange rate's impact on area of production and estimates its effect on the tropical and sub-tropical South American soybean industry. In doing so, I argue that one of the greatest comparative advantages available to South American farmers is an appreciated US dollar, as I show conceptually and in greater detail in the following section.

3.2 Theoretical model: Area Supply and the Rate of Exchange

The impact of currency fluctuations on international commodities production can be neatly expressed within a three-nation, profit maximizing model. Here excess soybean supply is traded between competing exporters and a collective entity representing an aggregate supply of importers, referred to here as ROW (rest of world). Consider nations a and b as exporters of commodity x, which use currencies α and β, respectively. ROW is taken as the global market for the total excess supply produced in both nations a and b of x, which is purchased in the international trade currency numéraire, currency α.

The rate of exchange (e_i) is defined as the value ratio between two currencies, e.g: $e_{\alpha\beta}= \alpha/\beta$ or $e_{\beta\alpha}= \beta/\alpha$. Appreciation in currency β occurs when β can be exchanged for more units of the currency numéraire, α, than previously, or where $\frac{de_{\beta\alpha}}{d\beta} > 0$. Depreciation wields precisely the opposite effect, or where $\frac{de_{\beta\alpha}}{d\beta} < 0$. Appreciation in currency β has the same effect on $e_{\beta\alpha}$ as a relative devaluation in α, given the relational aspect in currency exchange and valuation.

Aggregate excess demand, or import demand for x from ROW, responds to changes in global prices, γ_x , which apply internationally, e.g., the law of one price holds. Supply responses, however, are mediated by the rate of exchange between a local currency and the currency numéraire. In nation b, commodity x (p_{xb},) is thus determined not only by γ_x, but by the rate of exchange between β and α:

$$\gamma_x = p_{xb} e_{\beta\alpha} = p_{xb} \frac{\beta}{\alpha} \qquad (1)$$

$$\gamma_x \frac{\alpha}{\beta} = p_{xb} \qquad (2)$$

Because commodity x is traded on the global market in the currency of nation a, α, at price γ_x, $p_{x,a,} = \gamma_x$. Excess supply (S_i) from nation i[i= (a, b)] can now be formulated as a quasiconvex function of area (A_i) and price in terms of the domestic currency (p_{xi}).

$$S_i = g(p_{xi}, A_i) \quad \delta g/\delta p_{xi} > 0 \qquad (3)$$

Where:

$$A_{xi}^* = A_{xi}(p_{xi}, z_i) \qquad (4)$$

As indicated in equation 4, crop area can be expressed as a response to local commodity prices and a nation-specific set of constraints or enablers (z_i), with the latter set of variables accounting for factors such as quantity of available land and labor suitable for crop production. Evidently, a rise in p_{xi} will increase the area of production. By including the exchange rate as a determinant of p_{xi}, it can also be shown that local prices may rise in nation b even as they are falling in nation a, with area-supply responding accordingly.

This effect is shown graphically in figure panels 2a-2c , which show excess supply and demand changes for nations a, b, and ROW, respectively (Houck, 1986). For clarity, the global excess demand for commodity x is held constant (represented in purple in panel 1c). For nations a and b, the product quantity refers to excess production for each nation. The global price for commodity x, shown as the horizontal line, is represented across the three panels as γ(x).

Consider now the response to depreciation in currency β. Depreciation in β results in a positive shift in p_{xb} and the rotation of the excess supply curve [$S_b^0 \rightarrow S_b^1$] and excess demand [$D_b^0 \rightarrow D_b^1$] clockwise, with the end result being an increased supply from country b, Q_{xb}. As shown in panel C, the growth in excess supply from nation b is balanced by losses in production in nation a. Thus the relative appreciation of α decreases p_{xa}, and results in a loss of production. The actual area supply response depends on the elasticity of area supply with respect to price, which will vary by exporting nation. Generally, this response is higher in Latin America than in the US, where supplies of unused cropland are more limited (Barr et al., 2011). In figure panels 2a and 2b a cumulative increase in excess supply is shown as causing prices in ROW to fall slightly, as indicated by the fall in $\gamma(x)$ to $\gamma(x)'$.

If excess demand for commodity x is growing, as was the case for soybeans during the late 1990s and 2000s, then global prices for x may remain stable or grow slightly despite the depreciation, depending on the relative increase in excess supply in nation b to the increase in global demand. As will be shown in the following section, this is exactly what occurred in South America from 2003-2005, when both a weakened currency and heightened demand for soybeans resulted in a rise in global prices simultaneous to a favorable currency exchange.

The three nation model used here to illustrate the role of the exchange rate as a component in the process of international trade is clearly a simplification of today's global trade. Tariffs, export and import quotas, and other barriers to trade naturally will insulate the local from global prices. Nevertheless, the three nation model lends a particular utility to the present question of global trade in soybeans, where two regions (North and South America) supply imports to the remainder of the world.

3.3 Exchange and market effects

As noted in Section 2, incremental increases in the federal funds rate in 1994, intended to ward off inflation, triggered the appreciation of the US dollar. Residual impacts of the stronger dollar disseminated abroad, first with the Asian financial crisis in 1997 and later in South America, with currency devaluations in Brazil and Argentina. In Brazil, the real, subjected to a controlled devaluation since its introduction in 1995, floated for the first time in 1999 and promptly ceded nearly half of its value. By 2002, the currency had dropped to its lowest point, hitting 3.90$RS per 1$US. Paraguay, which had had a floating exchange rate, eluded some of the currency shocks endured by its neighbors Brazil and Argentina, but nevertheless faced the steady depreciation of its guaraní, falling from 1,793Gs:1$US to a low of 7,018Gs:1$US by 2003. In Bolivia, a similar trajectory emerged, if less severe. From 1995 to 2003, the Bolivian boliviano fell approximately 52 percent, from 4.76 to 7.27 per 1 $US (OANDA, 2010).

With devalued currencies, net revenues for soybean production reached a zenith in South America, despite a stabilization or decline in global commodity prices. Table 1 shows that despite a reduction in prices for soybeans in US dollars from 1996 to 2002, local prices for soybeans were in fact rising in the Southern Hemisphere (all prices have are normalized to year 2000 values). Thus even as global prices for soybeans were falling, farmers in Brazil, Paraguay and Bolivia were reaping the rewards of increasingly favorable economic conditions for production. To distinguish between the impacts of the global market, roughly constant across nations, and currency values in the formation of local prices, I distilled changes in local prices into a market effect (the change in price in US dollars) and an exchange effect, the impact of currency fluctuations. The market effect is the difference in the price of a commodity in US dollars from one time period to another. The exchange effect (in US$, E_i), is summarized as equation 5 or:

$$E_i = \frac{\Delta p_i - (\Delta \gamma_i * e_i)}{e_i} \quad (5)$$

where Δp_i is the change in price in local currency units, $\Delta \gamma_i$ is the change in the market price of soybeans (in US$) , and e_i is the average exchange rate during for a given period. Prices for soybeans in Brazil in both reales and US dollars are shown for in table 1. As indicated, in dollars prices fell in 1997 and remained low until 2002. Yet with the devaluation of the real, prices in the local currency surged higher. Thus even as global prices for soybeans were falling, currency devaluations created a favorable economic environment for soybean producers, where positive exchange effects from the late 1990s and the early 2000s provided incentives for new production during that period. Thus South American production grew rapidly during a period in which US production remained stable (figure 3). From 2002-2003, when both the exchange effect and the market effect were positive, South American farmers reaped some of the highest local prices for soybeans (figure 4). More recently, the rise in global food prices (e.g., late 2000s), has been offset, at least in Brazil, by the appreciation of the real and the weakened US dollar.

4. Statistical Methods

To model the impact of the exchange rate on the area of soybeans harvested in South America I first estimated the elasticity of soybean area harvested with respect to local prices. Data for local real prices (normalized to year 2000 US$) and harvested area were acquired from the Food and Agriculture Organization for the period 1990-2008 (Food and Agriculture

Organization, 2012). Average annual (bid) exchange rates for each nation were acquired from Oanda.com. Following recent work (Lin et al., 2000) elasticities of area with respect to changing producer incentives were calculated using nation specific changes in producer incentives. To control for country (or in the case of the Legal Amazon, region) specific attributes such as potential area of production, infrastructure, and political economy, elasticity measurements were evaluated separately for each nation.

A log-log model with distributed lagged dependent variables (t-1, t-2) was employed in the analysis, which estimated area supply responses, or the elasticity of area harvested with respect to local prices. Here I suggest that farmers make their planting decisions based on the expected price of the commodity that they intend to plant. Lacking price futures specific to each nation in this analysis, I have included time lagged price variables as a representative of the expected price. Additionally, I recognize that area in production is a function, in part, of fixed investments, which constrain adaptation to price signals. Consequently, I adopt a Nerlove partial adjustment model (Nerlove 1956) for this research, where the area of production in one year is a function of areas in production during past years, combined with the expected price for that product. The Nerlove model, which includes lagged observations of the dependent variable as right side explanatory variables, accounts for long run responses to past price expectations, as well as to the series of pre-existing structural constraints that may affect total production areas. Equally important, by including lagged dependent variables rather than a set of structural variables, the model accounts for temporal autocorrelation in the dependent variable (Adams et al., 1999, Wooldridge, 2000). Akaike Information Criteria tests indicated that either one or two lagged dependent variables were appropriate, depending on the nation in question. For consistency, two lagged dependent variables were used in each estimation. The resultant model appears as:

$$\ln Y_{it} = \beta_0 + \phi \ln Y_{it-1} + \eta \ln Y_{it-2} + \psi \ln L_{it-1} + \varepsilon \qquad (6)$$

Where Y is the area of soybeans harvested, L is the local price for soybeans in local currency units and ε is idiosyncratic error. The subscripts *t* and *i* represent year and nation, respectively. The parameters estimated included β, Φ, η, and ψ.

The model was applied to four regions; Brazil, Paraguay, Bolivia, and a nine state Brazilian political entity known as the Legal Amazon. The Legal Amazon, where area responses are likely to be higher, given the comparative availability of land in this region, was also analyzed separately from the rest of Brazil. The estimated coefficients for ψ for each nation are as follows: Brazil, 0.32 (0.19-0.47, 95% confidence interval); Legal Amazon, 0.47 (0.26-0.67); Paraguay, 0.17 (0.07-0.27); Bolivia, 0.28 (0.08-0.48). Adjusted R^2s for the four models ranged from 0.94 (Bolivia) to 0.99 (Paraguay). The full model results are reported in Table 2. The calculated elasticities are slightly higher than those estimated by Barr, et al. (2011), who estimated area elasticities of between 0.44 (with a two year lag) and 0.162, for all cropland and returns (rather than for soybeans and price, as was used in this analysis) for various time periods during the past 15 years in Brazil.

The estimated coefficients for elasticity with respect to local prices were used in the two counterfactual simulation models, with *L* being replaced by *E*, exchange rate, and γ, local soybean price in US dollars. The model simulation is dynamic, with the estimated changes in area based off of the areas estimated during the previous time periods. The resultant model appears as equation 7:

$$\ln Y_{it} = \beta_0 + \phi \ln \hat{Y}_{it-1} + \eta \ln \hat{Y}_{it-2} + \psi \ln E_{it-1} + \psi \ln \gamma_{it-1} + \varepsilon \qquad (7)$$

Note that lnL_{ti} is approximately equal to $lnE_{ti} + ln\gamma_{ti}$.

To estimate the impact of currency fluctuations on soybean area I tested two counterfactual models for each region. I first considered the impact of the appreciated US dollar and depreciated local currencies by simulating growth in soybean area with exchange rates pegged to the low rates of 1995. A second set of counterfactual models was also conducted to estimate the growth of soybean areas if the strong dollar of the 1990s had been maintained. In the counterfactual models both the global market prices and the exchange rates are kept at their historical values. As indicated in section 3.2, a supply increase from the South American nations as is indicated in the simulations would likely have caused global prices to stagnate or depress, as happened at the end of the last millennium. It is also likely that significant growth in agricultural exports would have positively affected the value of the currency in question, a la the so-called Dutch disease effect. As neither of the effects is accounted for in the counterfactual simulations, and I recognize that the estimates produced may be skewed upwards.

5. Results and Counterfactual Simulations

The results of the counterfactuals are summarized in table 3 and figures 5a-5d. They suggest that the devaluation of the Brazilian real contributed to the creation of an additional 63,000km² of soybean production, or 29 percent of the nation's 2009 total, since 1996. Within the Legal Amazon, a region that demonstrates a higher area supply response to local prices given the relative availability of land, 28,000km² of additional soybean areas were brought into production, accounting for 43 percent of the region's total soybean area. In Paraguay, an exchange rate pegged to 1993 levels would have held soybean production at less than half of its current levels; in Bolivia, with the exchange rate held to 1995 levels, the area of soybean production would be at only three-quarters of its current extent. In total, I estimate that currency depreciation resulted in over 78,000km² of new soybean fields, approximately 60 percent of the increase in area across Brazil, Paraguay, and Bolivia (since 1996, 1994, and 1995 respectively) and 31 percent of the current extent.

The second counterfactual, under which currency lows reached during the mid-2000s were sustained through the end of the decade, was also tested. This second set of simulations suggested that, had the real-dollar exchange rate remained at 3.04$BR:1$US (the average exchange rate in Brazil in 2002), an additional 83,000km² would have been brought into production since 2003. In the Amazon, the impact would have also been substantial; soybean production would have reached 103,737km², 60 percent more than presently. In Paraguay, where revaluation of the guaraní was minimal and later (low average annual currency values were not reached until 2003), 4,300km² were spared from production after 2003. In Bolivia, an additional 1,700km² were spared from 2005. The full results of the models, including the predicted areas (in km²) and the results of the two counterfactual simulations are included as Tables S.1-S.4 in the appendix.

6. Discussion

The ecological impacts associated with the expansion of South American agriculture have already been shown as large, and have accordingly drawn the concern of researchers working on global land use change issues (Nepstad et al., 2006, Simon and Gargorry, 2005, Kaimowitz and Smith, 2001, Walker et al., 2009a). It follows that as incentives for agricultural production in the Amazon increase, new lands are likely to be brought into production, presumably at the expense of existing pastures or natural land covers (Barona et al., 2010, Arima et al., 2011, Richards, 2011b).

I recognize that in the Brazilian Amazon, ground zero for tropical deforestation during the past decade, cattle production continues to be the principal driver of forest loss (Margulis, 2004, Faminow, 1998). From the cattle sector's initial entry into the region in the 1960s, ranching has proved itself to be persistent as the principal driver of South America's agro-pastoral frontier (Hecht and Cockburn, 1989). In most recent decades, however, the Amazonian range too has turned global. The eradication of foot and mouth disease and an increasing flow foreign and national investment in the region's ranching sector have driven an expansion in slaughterhouse and export capacity; more generally, the explosion in cattle production in this region has led the way for Brazil to overtake Australia as the world's leading beef exporter (Walker et al., 2009b, Nepstad et al., 2006). As this region becomes increasingly connected to both national and international markets, it is also likely to be increasingly sensitive to the dynamics of global financial markets.

In this paper I have focused not on cattle ranching, but on the expansion of agricultural lands. Evidence has already linked the growth of soybean production directly to forest loss in South America, particularly across northern Mato Grosso state in Brazil (Galford et al., 2008, Morton et al., 2006). Concerns about the environmental impacts of cropland expansion have also been documented in the relatively less studied forest regions of Paraguay and Bolivia, where the Atlantic and Amazon forests have been severely decimated in recent decades (Steininger et al., 2001, Richards, 2011a, Huang et al., 2007). More recently, discussions regarding the possibility of indirect land use change or land use displacement associated with cropland expansion in South America have also emerged, particularly in relation to the expansion of agricultural land in Brazil. Research has suggested that the conversion of cattle pastures to create new croplands may be resulting in the displacement of the human and financial capital tied to their production (Lapola et al., 2010, Barona et al., 2010, Arima et al., 2011, Richards, 2011b). If displaced ranchers reconstitute their operations on the frontier, then it follows that, indirectly, the environmental impacts of expanded soy production may be of greater importance than previously realized. In any case, both soybeans and beef are traded commodities and have been linked, whether directly or indirectly, to regional losses in tropical forest cover.

Plotting Amazonian deforestation against the real-dollar exchange rate is suggestive of a correlation between the two trends. Deforestation remained acute while the Brazilian real remained weak from 1999-2005, but declined with its appreciation and the depreciation of the US dollar (Figure 5). More recently, in 2009, as the Brazilian real strengthened to its highest value against the US dollar in the past ten years, both agricultural expansion and deforestation in Brazil slowed, with forest loss in the Amazon dropping to 7,464km², the lowest level seen in the past two decades. Given that the appreciation of the real likely reduced not only incentives for the production of agricultural exports, but also for beef exports, then it follows that the pressure for continued expansion for the production of these crops would also be diminished. By linking agricultural expansion in South America to the appreciation of the US dollar, I thus warn that a strong US dollar may carry the indirect effect of outsourcing environmental degradation associated with agricultural expansion to beyond the nation's border. Conversely, the appreciation of the real is likely to abate pressure for the economic development and environmental degradation of the Amazon.

7. Conclusion

Global consumption of soybean products increased rapidly during the past two decades. Between 1995 and 2006 soybean production also expanded rapidly, particularly in South

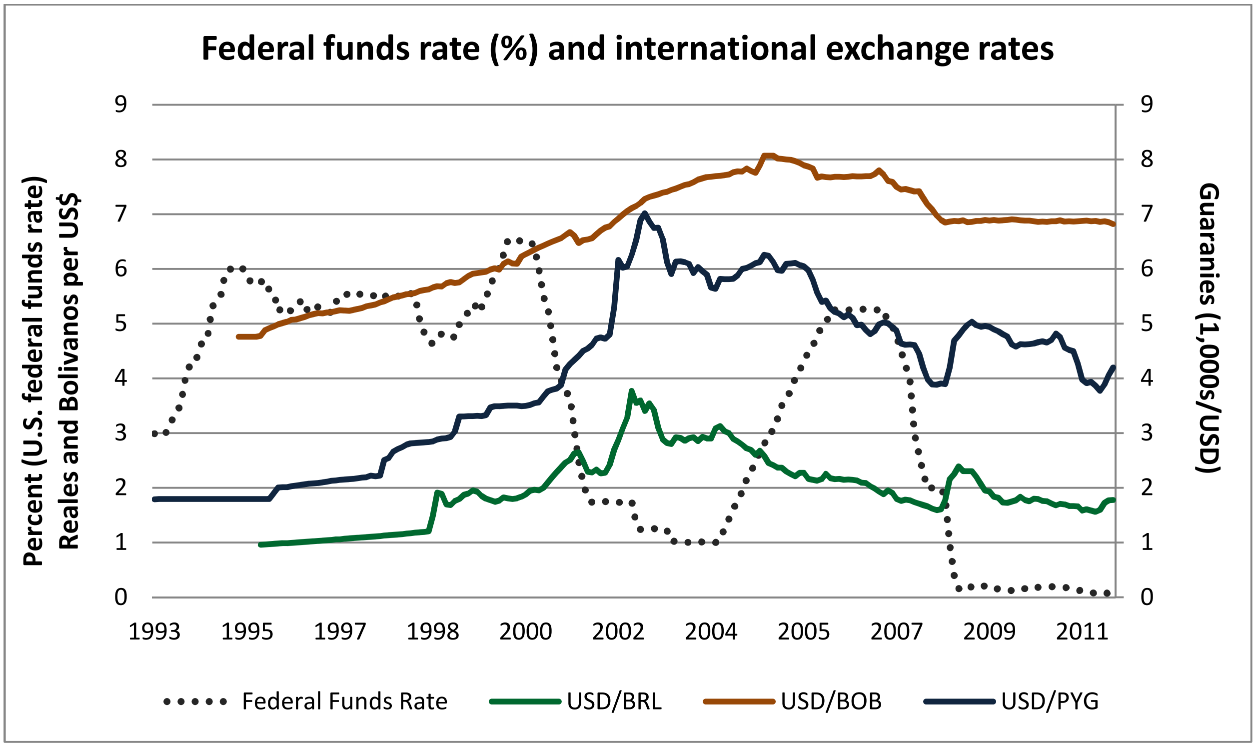
America. This rapid expansion in South American production, however, occurred despite a stagnation in global prices for soybeans and their derivatives: soybean meal and soybean oil (Food and Agriculture Organization, 2011a). This phenomenon, I suggest, is owing to a favorable exchange rate for South American producers during this time period.

As global commodity chains continue to become more efficient, supply responses will increasingly depend not only on the physical limitations of producing regions across the globe, nor the incentives for competing land uses, but on the relative value of a nation's currency. In this sense, currency exchanges must be recognized as a comparative advantage that will occupy an important role in the global sourcing of agricultural commodities.

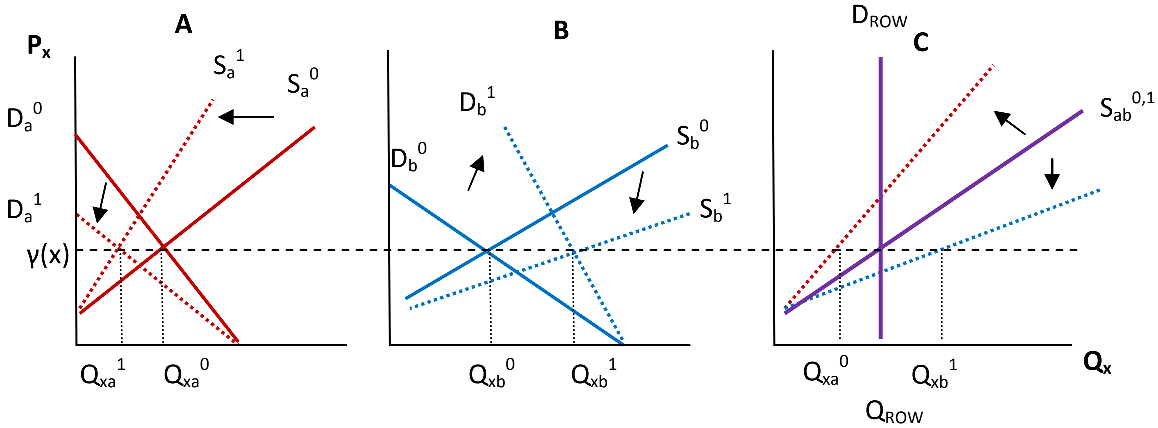
In conclusion, the findings suggest that the appreciation of the US dollar during the late 1990s reshaped agriculture in tropical and sub-tropical South America, with potential implications for the region's forests, carbon reserves, and traditional farming systems.   Today, the US federal funds rates remain close to zero, with the US struggling to emerge from one of the deepest recessions since World War II. Deforestation in Brazil and Paraguay also are down, with rates of Amazonian forest loss at their lowest points in decades. However, if the US dollar once again appreciates to levels reached at the turn of the millennium, farmers in South America may again be presented with extraordinary incentives to expand production. Policy makers must then be prepared to answer the timely questions that will emerge concerning rural livelihoods, ecological sustainability and South America's emerging land-based economy.

Figures and Tables

Figure 1

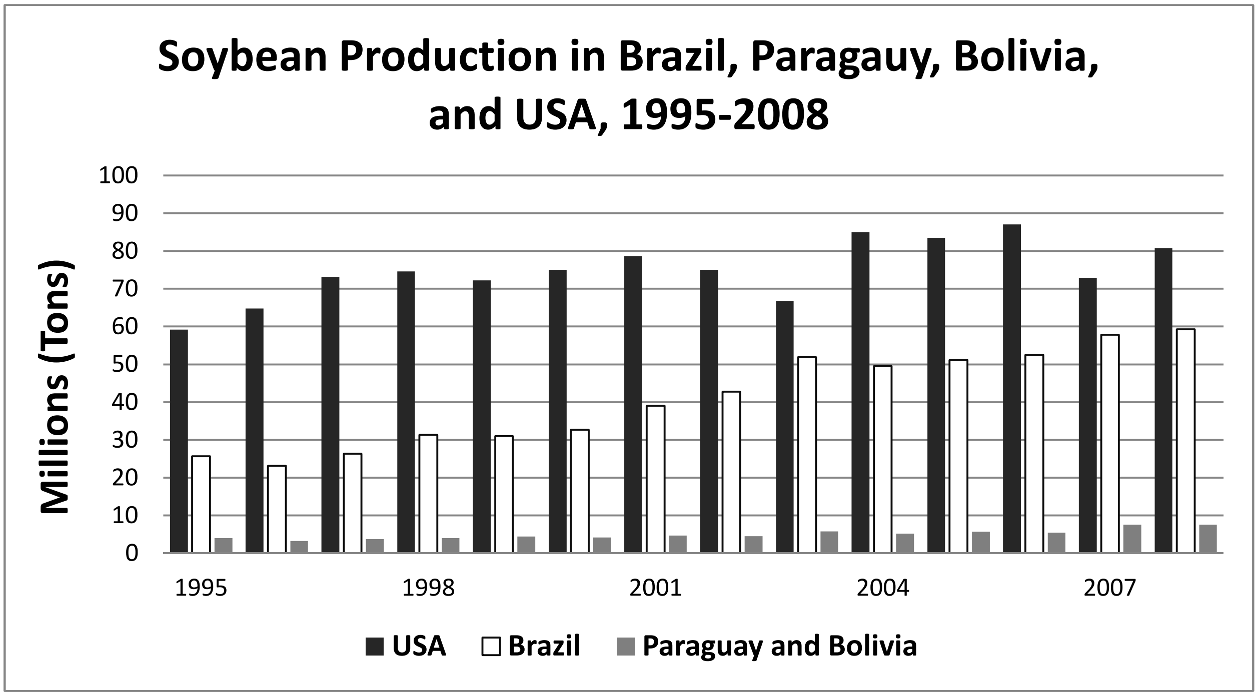


Figures 2a-2c



Graphs indicating excess supply responses to currency devaluation in nation b by nations a (left), b (center), and Rest of World (ROW) (right).

Figure 3



Soybean Production in Brazil, Paraguay and Bolivia, 1995-2008. Data from FAOSTAT (2011)

Figure 4

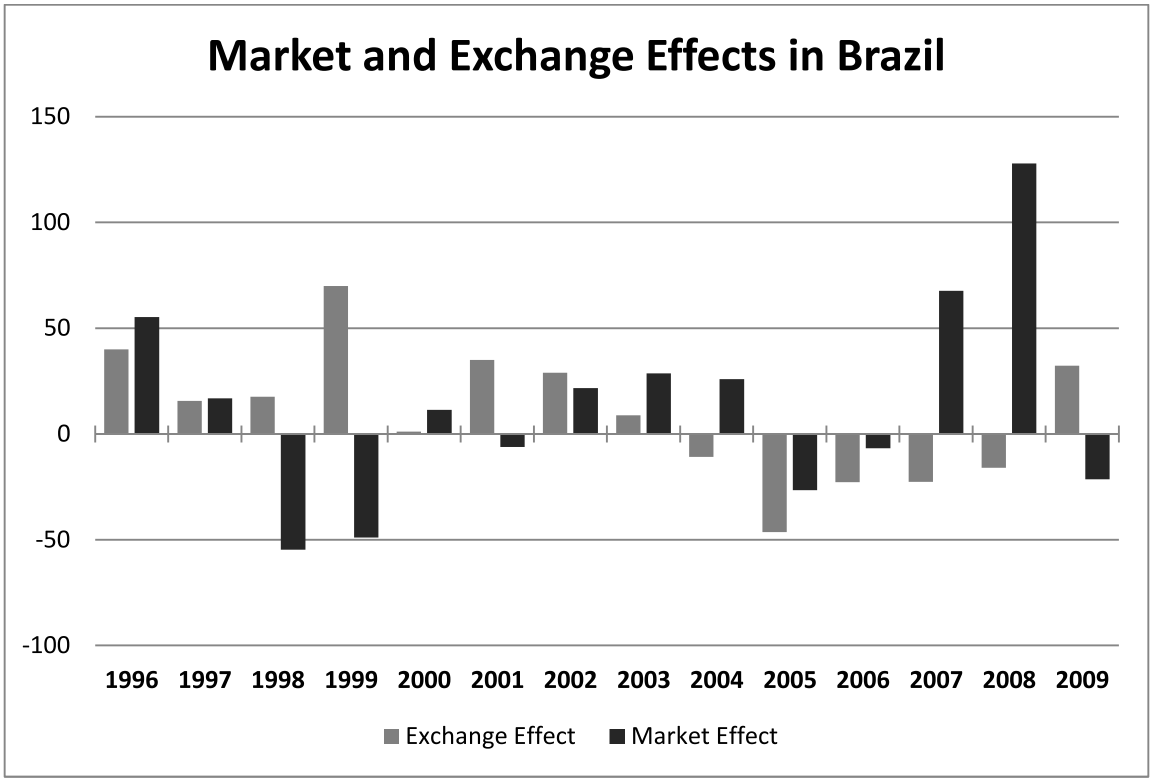
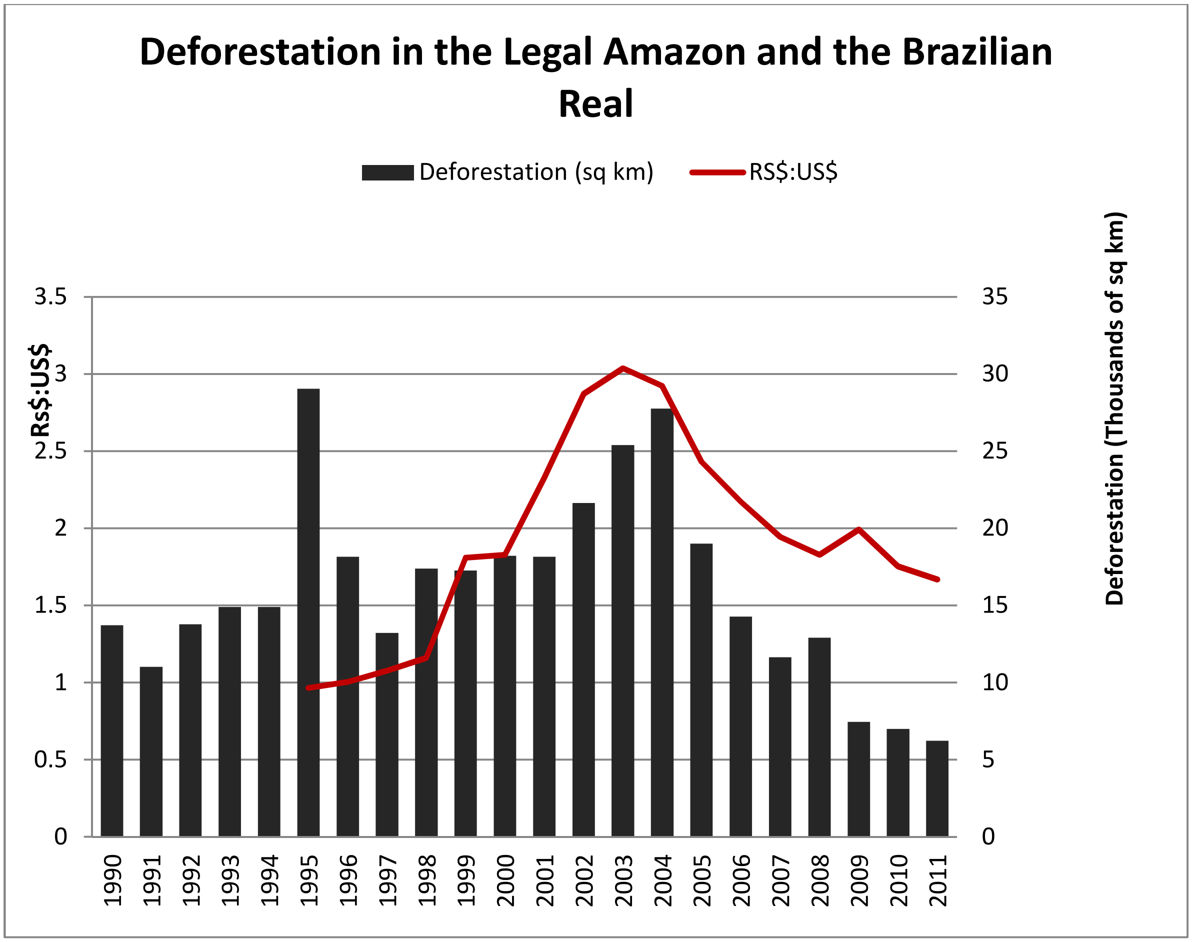


Chart indicating the market and exchange effects in Brazil, 1996-2009. Soybean prices during the duration of the soybean boom (1998-2003) declined or stagnated in dollars.

Figure 5



Deforestation in the Legal Amazon region (INPE 2011) and the real-dollar exchange rate

Table 1

Soybean price changes by market and exchange effect in Brazil (US$)

	Price(ton) in US$	Price(ton) in BR$	Exchange Rate BR/US	Market Effect	Exchange Effect
1996	231.8	233	1.01	55.3	15.33
1997	248.6	268	1.08	16.8	15.67
1998	193.9	225	1.16	-54.7	17.64
1999	144.9	263	1.82	-49	69.94
2000	156.3	286	1.83	11.4	1.17
2001	150.1	354	2.36	-6.2	35.03
2002	171.8	502	2.92	21.7	28.88
2003	200.4	617	3.08	28.6	8.77
2004	226.3	661	2.92	25.9	-10.80
2005	199.8	484	2.42	-26.5	-46.37
2006	193.1	420	2.18	-6.7	-22.82
2007	260.7	508	1.95	67.6	-22.65
2008	388.5	713	1.83	127.8	-16.02
2009	367.1	734	2.00	-21.4	32.25

Table 2: Model Results

Model	Model 4: Brazil		Model 1: Legal Amazon		Model 3: Paraguay		Model 2: Bolivia	
Time	1995-2009		1995-2009		1991-2009		1991-2009	
Number observs.	14		14		18		18	
Prob < F	0.00		0.00		0.00		0.000	
R-square	0.98		.98		0.99		0.95	
Adjusted R-square	0.97		.97		0.99		0.94	
Root MSE	0.05		0.07		0.04		0.12	
	Coef (se)	**(p>|t|**	**Coef (se)**	**(p>|t|**	**Coef (se)**	**(p>|t|**	**Coef (se)**	**(p>|t|**
LNSoybean Area t-1	0.52 (0.18)	0.2	0.45 (0.18)	0.04	0.64 (0.09)	0.00	0.78 (0.26)	0.01
LNSoybean Area t-2	-0.06 (0.15)	0.68	0.05 (0.16)	0.75	0.17 (0.08)	0.06	-0.08 (0.24)	0.74
LN Soybean Price	0.32 (0.06)	0.00	0.47 (0.09)	0.00	0.17 (0.04)	0.00	0.28 (0.09)	0.01

Table 3
Actual and Simulated Soybean Areas (km²)

	Brazil			Legal Amazon		
	Actual	CF1[1]	CF2[2]	Actual	CF1[1]	CF2[2]
Soybean Area (2009)	217,602	154,673	301,363	64,765	36,964	103,737
Difference from Actual	0	-62,929	83,761	0	-27,801	38,972
Percent Difference	0	-29%	38%	0	-43%	60%
	Paraguay			**Bolivia**		
	Actual	CF1[3]	CF2[4]	Actual	CF1[5]	CF2[6]
Soybean Area (2009)	25,154	12,081	29,484	9,796	7,318	11,520
Difference from Actual	0	-13,073	4,330	0	-2,478	1,724
Percent Difference	0	-52%	17%	0	-25%	18%

[1] 1.01BR$:1US$ after 1996 [2]3.04BR:1US$ after 2002 ;[3] 1792Gs:1US$ after 1993 ; [4] 6361Gs:1US$ after 2003; [5]4.79BO:1US$L after 1995; [6] 7.96Bol:1US$ after 2005

Table S1: Legal Amazon (km²)				
	Actual	Predicted	CF1 1.02$RS:1 $US	CF2 3.06$RS:1 $US (after 2002)
1997	23258.91	24803.86	24803.86	24803.86
1998	28480.56	28749.78	27801.85	28749.78
1999	28517.68	29450.16	26304.95	29450.16
2000	31503.08	31211.69	22508.64	31211.69
2001	34329.62	33492.91	21691.64	33492.91
2002	41886.18	38295.68	20765.45	38295.68
2003	48881.91	48941.88	21657.70	48941.88
2004	59443.88	58026.99	23673.22	59129.07
2005	67792.43	66556.64	26140.70	69004.15
2006	64831.19	61262.91	25890.56	70419.24
2007	57186.68	56047.10	25499.61	70491.62
2008	63431.41	58004.86	29152.06	81301.96
2009	64,765.21	71,311.81	37,309.21	104,550.24

Table S2: Brazil (km²)				
	Actual	Predicted	CF1 1.02$RS:1 $US	CF2 3.06$RS:1 $US (after 2002)
1997	114,865.00	105367.95	105367.95	105367.95
1998	133,037.00	126110.57	123213.83	126110.57
1999	130,614.10	131559.18	121438.25	131559.18
2000	136,400.26	136679.70	108512.26	136679.70
2001	139,743.00	143301.06	104956.94	143301.06
2002	163,654.00	156993.09	102524.26	156993.09
2003	185,247.69	186213.84	106055.51	186213.84
2004	215,389.90	210102.68	113679.56	212860.41
2005	229,488.74	228917.21	122387.21	234952.71
2006	220,473.49	213681.73	121608.21	235556.68
2007	205,653.00	196774.96	119298.74	231799.54
2008	212,717.62	199868.37	130300.29	253441.47
2009	217,602.08	232,010.09	155,599.79	302,756.87

Table S3: Paraguay (km²)				
	Actual	Predicted	CF1 1791Gs:1 $US	CF2 6089Gs:1 $US (after 2003)
1994	6941.17	7151.57	7151.57	7151.57
1995	7355.03	7782.46	7781	7782.46
1996	8330.05	8124.26	8121	8124.26
1997	9396.52	9135.42	8917.11	9135.42
1998	10860.43	10187.08	9685.64	10187.08
1999	11657.50	11160.00	9995.85	11159.99
2000	11764.60	11339.31	9498.88	11339.31
2001	13500.00	12928.12	10104.88	12928.11
2002	14453.60	13187.19	9450.31	13187.18
2003	14741.48	14531.75	9191.62	14531.75
2004	18700.00	17425.33	9948.94	17425.32
2005	19700.00	19984.28	10556.29	20170.59
2006	22000.00	21679.49	10640.99	21880.03
2007	24000.00	22949.84	10865.64	23769.72
2008	26450.00	24725.45	11466.52	26430.64
2009	25,154.31	26,049.23	12,075.54	29,090.46

Table S4: Bolivia (km^2)				
	Actual	Predicted	CF1 4.83BOL:1$US	CF2 7.98BOL:1 $US (after 2005)
1996	4632.43	3796.67	3796.67	3796.67
1997	5270.50	4380.96	4308.16	4380.96
1998	5886.10	5246.52	5046.11	5246.52
1999	6278.70	5642.02	5266.16	5642.02
2000	6169.64	5897.58	5314.03	5897.58
2001	6152.92	6008.51	5190.93	6008.51
2002	6371.24	6125.94	5055.13	6125.94
2003	6842.13	6462.18	5066.06	6462.18
2004	8039.90	6981.85	5180.30	6981.85
2005	9410.68	7843.87	5546.12	7843.87
2006	9501.18	8330.33	5648.82	8330.33
2007	9582.79	8505.72	5662.88	8594.39
2008	7857.93	9270.71	6128.72	9479.81
2009	9,796.78	10,954.11	7,378.39	11,556.17

References

ADAMS, D. M., ALIG, R. J., MCCARL, B. A., CALLAWAY, J. M. & WINNETT, S. M. 1999. Minimum Cost Strategies for Sequestering Carbon in Forests. *Land Economics,* 75**,** 360-374.

ANDERSEN, L., GRANGER, C., REIS, E. J., WEINHOLD, D. & WUNDER, S. 2002. *The Dynamics of Deforestation and Economic Growth in the Brazilian Amazon,* Cambridge, Cambridge University Press.

ANDERSON, D. P., MINERT, J. & BRESTER, G. 1989. The North American Livestock Industry: A U.S. Perspective. *In:* LYONS, R. M. A., KNUTSON, R. D. & MEIKE, K. (eds.) *Economic Harmonization in the Canadian/U.S./Mexican Grain-Livestock Subsector.* . Winnipeg, Manitoba: Texas A&M University/University of Guelph.

ARCAND, J.-L., GUILLAUMONT, P. & JEANNENEY, S. 2008. Deforestation and the real exchange rate. *Journal of Development Economics,* 75**,** 242-262.

ARIMA, E., RICHARDS, P. D., WALKER, R. & CALDAS, M. 2011. Statistical Confirmation of Indirect Land Use Change in the Amazon. *Environmental Research Letters,* 6.

BAIG, T. & GOLDFAJN, I. 1999. Financial Market Contagion in the Asian Crisis. *IMF Staff Papers,* 46**,** 167-195.

BARNHAM, B. L. & COOMES, O. T. 1994. Reintrepeting the Amazon Rubber Boom: Investment, the State, and Dutch Disease. *Latin American Research Review,* 29**,** 73-109.

BARONA, E., RAMANKUTTY, N., HYMAN, G. & COOMES, O. 2010. The role of pasture and soybean in deforestation of the Brazilian Amazon. *Environmental Research Letters,* 5.

BARR, K. J., BABCOCK, B. A., CARRIQUIRY, M. A., NASSAR, A. M. & HARFUCH, L. 2011. Agricultural Land Elasticities in the United States and Brazil. *Applied Economic Perspectives and Policy,* 33**,** 449-462.

BRANDÃO, A., REZENDE, G. & MARQUES, R. 2006. Crescimento agrícola no período 1999/2004: a explosão da soja e da pecuária bovina e seu impacto sobre o meio ambiente (Agricultural growth in the period 1999/2004: The explosion of ranching and its impacto on the environment). *Economics Applied* 10**,** 249-266.

BRANDÃO, A. S. P., REZENDE, G. C. D. & MARQUES, R. W. D. C. 2005. Crescimento Agricola no Periodo 1999-2004, Explosao da Area Plantada com Soja e Meio Ambiente no Brasil. *TEXTO PARA DISCUSSÃO N° 1062.* Rio de Janeiro: Instituto de Pesquisa Economica Aplicada.

BRANNSTROM, C., JEPSON, W., FILLIPPI, A., REDO, D., XU, Z. & GANESH, S. 2007. Land Cover Change in the Brazilian Savanna (Cerrado), 1986-2002; Comparative analysis and implications for land use policy. *Land Use Policy,* 25**,** 579-595.

BROWN, J. C., KOEPPE, M., COLES, B. & PRICE, K. 2005. Soybean production and conversion of tropical forest in the Brazilian Amazon: the case of Vilhena, Rondônia *Ambio,* 34**,** 462-469.

CHAMBERS, R. G. 1981. Interrelationships between Monetary Instruments and Agricultural Commodity Trade. *American Journal of Agricultural Economics,* 63**,** 934-941.

CHAMBERS, R. G. (ed.) 1988. *An Overview of Exchange Rates, Macroeconomics, and Agriculture*: Westview Press.

CORDEN, W. M. 1984. Booming Sector and Dutch Disease Economics: Survey and Consolidation. *Oxford Economic Papers,* 36**,** 359-380.
CORSETTI, G., PESENTI, P. & ROUBINI, N. 1999. What Caused the Asian Currency and financial crisis? *Japan and the World Economy,* 11(1999)**,** 305-373.
DEFRIES, R. S., RUDEL, T., URIARTE, M. & HANSEN, M. 2010. Deforestation driven by urban population growth and agricultural trade in the twenty-first century. *Nature Geoscience,* 3**,** 178-181.
ECONOMIC RESEARCH SERVICES 2001. Exchange Rate Indexes and U.S. Ag Trade. *Agricultural Outlook.* Economic Research Service/United States Department of Agriculture.
EWERS, R., LAURANCE, W. & SOUZA, C. 2008. Temporal fluctuations in Amazonian deforestation rates. *Environmental Conservation,* 35**,** 303-310.
FAMINOW, M. 1998. *Cattle, Deforestation and Development in the Amazon: An Economic, Agronomic and Environmental Perspective*, Cabi.
FOOD AND AGRICULTURE ORGANIZATION. 2011a. *Price Stat* [Online]. Rome: Food and Agriculture Organization. Available: http://faostat.fao.org [Accessed January 2012].
FOOD AND AGRICULTURE ORGANIZATION. 2012. *Crop Statistics by Country* [Online]. Rome: Food and Agriculture Organization. Available: faostat.fao.org [Accessed January 2012].
FOOD AND AGRICULTURE ORGANIZATION, F. 2011b. *TradeStat* [Online]. Rome: Food and Agriculture Organization. Available: faostat.fao.org [Accessed January 2012].
FOREIGN AGRICULTURAL SERVICE 2010. 2011 Forecast: Trade Higher on Broiler Meat and Beef Demand. *Livestock and World Market.* United States Department of Agriculture Foreign Agricultural Service.
GALFORD, G., MUSTARD, J., MELILLO, J., GENDRIN, A., CERRI, C. C. & CERRI, C. E. P. 2008. Wavelet analysis of MODIS time series to detect expansion and intensification of row-crop agriculture in Brazil. *Remote Sensing of Environment,* 12**,** 576-587.
GRIGSBY, S. E. & ARNADE, C. A. 1986. The Effect of Exchange Rate Distortions on Grain Export Markets, The Case of Argentina. *American Journal of Agricultural Economics Applied,* 68**,** 434-440.
HECHT, S. & COCKBURN, A. 1989. *The fate of the forest : developers, destroyers, and defenders of the Amazon,* New York, Verso.
HECHT, S. B. & MANN, C. 2008. How Brazil Outfarmed The American Farmer. *Fortune.*
HELFAND, S. & REZENDE, G. C. D. 2004. The impact of Sector-Specific and Economy-Wide Policy Reforms on the Agricultural Sector in Brazil: 1980-1998. *Contemporart Economic Policy,* 22**,** 194-212.
HOOPER, P. & KOHLHAGEN, S. W. 1978. Journal of International Economics. *8***,** 483-511.
HOUCK, J. P. 1986. *Elements of Agricultural Trade Policies,* New York, MacMillan.
HUANG, C., KIM, S., ALSTATT, A., TOWNSHEND, J., DAVIS, P., SONG, K., TUCKER, C., RODAS, O., YANOSKY, A., CLAY, R. & MUSINSKIY, J. 2007. Rapid loss of Paraguay's forest and the status of protected areas- A Landsat assessment. *Remote Sensing of the Envrionment,* 106**,** 460-466.
JEPSON, W. 2006. Producing a modern agricultural frontier: Firms and cooperatives in Eastern Mato Grosso, Brazil. *Economic Geography,* 82**,** 289-316.

JEPSON, W., BRANNSTROM, C. & FILIPPI, A. 2010. Regimes and Regional Land Change in the Brazilian Cerrado, 1972-2002. *Annals of the Association of the American Geographers,* 100**,** 87-111.
KAIMOWITZ, D. & SMITH, J. (eds.) 2001. *Soybean Technology and the Loss of Natural Vegetation in Brazil and Bolivia,* New York: CABI Publishing.
KOST, W. E. 1976. Effects of an Exchange Rate Change on Agricultural Trade. *Agricultural Economics Research,* 28**,** 99-106.
LAMBIN, E. & MEYFROIDT, P. 2011. Global land use change, economic globalization, and the looming land scarcity. *Proceedings of the National Academy of Sciences of the United States of America,* 108**,** 3465-3472.
LAMBIN, E. F. & MEYFROIDT, P. 2010. Land use transitions: Socio-ecological feedback versus socio-economic change. *Land Use Policy,* 27**,** 108-118.
LAPOLA, D. M., SCHALDACHA, R., ALCAMOA, J., BONDEAUD, A., KOCHA, J., KOELKINGA, C. & PRIESSE, J. A. 2010. Indirect land-use changes can overcome carbon savings from biofuels in Brazil. *Proceedings of the National Academy of Sciences of the United States of America*.
LIN, W., WESTCOTT, P. C., SKINNER, R., SANFORD, S. & UGARTE, D. 2000. *Supply Response Under the 1996 Farm Act and Implications for the U.S. Field Crops Sector*, Market and Trade Economics Division, Economic Research Service, U.S. Department of Agriculture.
LONGMIRE, J. & MOREY, A. 1983. Strong Dollar Dampens Demand for U.S. Farm Exports. Washington DC: U.S. Department of Agriculture, ERS For Agricultural Economics.
MARGULIS, S. 2004. *Causes of Deforestation of the Brazilian Amazon,* Washington D.C., World Bank.
MASUDA, T. & GOLDSMITH, P. D. 2009. World Soybean Demand: An Elasticity Analysis and Long-Term Projections. Urbana, Illinois: National Soybean Research Laboratory University of Illinois at Urbana-Champaign.
MATTSON, J. W., WACHENHEIM, C. J., KOO, W. W. & PETRY, T. A. 2001. Canadian Exports of Livestock and Meat to the United States. *Agribusiness & Applied Economics Report No. 459.* Fargo, North Dakota: Center for Agricultural Policy and Trade Studies, North Dakota State University.
MORTON, D. C., DEFRIES, R., SHIMABUKURO, Y. E., ANDERSON, L. O., ARAL, E., DEL BON ESPIRITO-SANTO, F., FREITAS, R. & MORISETTE, J. 2006. Cropland expansion changes deforestation dynamics in the southern Brazilian Amazon. *Proceedings of the National Academy of Sciences of the United States of America,* 103**,** 14637-14641.
NAYLOR, R., LISKA, A., BURKE, M., FALCOM, W., GASKELL, J., ROZELLE, S. & CASSMAN, K. 2007. The Ripple Effect: biofuels, food security and the environment. *Environment,* 49**,** 30-43.
NAYLOR, R., STEINFEILD, H., FALCON, W., GALLOWAY, J., V., S., BRADFORD, E., ALDER, J. & MOONEY, H. 2005. Losing the Links between Livestock and Land. *Science,* 310**,** 1621-1622.
NEPSTAD, D., STICKLER, C. M. & ALMEIDA, O. 2006. Globalization of the Amazon Soy and Beef Industries: Opportunities for Conservation. *Conservation Biology,* 20**,** 1595-1603.

NERLOVE, M. 1956. Estimates of Elasticities of Supply of Selected Agricultural Commodities. *Journal of Farm Economics*, 38 (2) 496-509.

OANDA. 2010. *Average Exchange Rates* [Online]. Available: http://www.oanda.com/currency/average [Accessed].

PFAFF, A. 1999. What Drives Deforestation in the Brazilian Amazon?, : Evidence from Satellite and Socioeconomic Data. *Journal of Environmental Economics and Management,* 37**,** 26-43.

RICHARDS, P. 2011a. Cotton, Soy, and the Final Atlantic Forest Frontier. *The Professional Geographer,* 63**,** 1-21.

RICHARDS, P. D. 2011b. Food, Fuel, and the Hidden Margins of Capital. *Journal of Land Use Science*.

RUDEL, T., SCHNEIDER, L., URIARTE, M., TURNER, B. L., DEFRIES, R., LAWRENCE, D., GEOGHEGAN, J., HECHT, S. B., ICKOWITZ, A., LAMBIN, E. F., BIRKENHOLTZ, T., BAPTISTA, S. & GRAU, R. 2009. Agricultural intensification and changes in cultivated areas, 1970-2005. *Proceedings of the National Academy of Sciences of the United States of America,* 106.

SCHUH, E. 1974. The Exchange Rate and U. S. Agriculture. *American Journal of Agricultural Economics,* 56**,** 1-13.

SCHUH, E. 1976. The New Macroeconomics of Agriculture. *American Journal of Agricultural Economics,* 58**,** 802-811.

SIMON, M. F. & GARGORRY, F. L. 2005. The expansion of agriculture in the Brazilian Amazon. *Environmental Conservation,* 32**,** 203-212.

STEININGER, M. K., TUCKER, C. J., TOWNSHEND, J. R. G., KILLEEN, T. J., DESCH, A., BELL, V. & ERSTS, P. 2001. Tropical deforestation in the Bolivian Amazon. *Environmental Conservation,* 28**,** 127-134.

TILMAN, D., CASSMAN, K. G., MATSON, P., NAYLOR, R. & POLASKY, S. 2002. Agricultural sustainability and intensive production practices. *Nature,* 418**,** 671-977.

TURNER, B. L., LAMBIN, E. & REENBERG, A. 2007. The emergence of land change science for global environmental change and sustainability. *Proceedings of the National Academy of Sciences of the United States of America,* 104**,** 20666-20671.

WALKER, R., BROWDER, J., ARIMA, E., SIMMONS, C., PEREIRA, R., CALDAS, M., SHIROTA, R. & DE ZEN, S. 2009a. Ranching and the new global range: Amazônia in the 21st century. *Geoforum,* 40**,** 732-745.

WALKER, R., DEFRIES, R. S., VERA-DIAZ, M. D. C., SHIMABUKURO, Y. & VENTURIERI, A. 2009b. The Expansion of Intensive Agriculture and Ranching in Brazilian Amazonia. *In:* KELLER, M. (ed.) *Amazonia and Global Change.* Washington D.C.: American Geophysical Union.

WARNKEN, P. F. 1999. *The Development and Growth of the Soybean Industry in Brazil,* Ames, Iowa, Iowa State University Press.

WOOLDRIDGE, J. M. 2000. *Introductory econometrics : a modern approach,* Cincinnati, OH, South-Western College.

WUNDER, S. 2000. *The Economics of Deforestation: The Example of Ecuador,* New York, St. Martin's Press.