INDIRECT LAND USE CHANGE AND THE FUTURE OF THE AMAZON

By

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ABSTRACT

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In this research I consider several of the less understood aspects of agricultural land use change, an issue at the heart of a broader discussion on the tradeoffs between economic development and environmental conservation. I focus specifically on a region of rapid agricultural change, namely the Brazilian Amazon, where agricultural and beef production have tripled in recent decades, and more than 200,000 square kilometers of forest areas have been destroyed.

Specifically, this dissertation contributes to our understanding of the impacts of land use change by focusing on the so-called indirect effects associated with expanding agricultural production, or how production changes in one location may lead to changes in behaviors and land uses in another, potentially distant location. To date, much of the work on indirect land use change has conceptualized the process as a series of indirect effects originating from market dynamics and policies. Here I present another conceptual element to this process, namely an investment effect where skills and capital are liquidated and spatially (re)distributed over a landscape, perpetually in flux and in chase of rents and investment opportunities. The Brazilian Amazon, a region that has undergone rapid changes in forest cover, pasture, and cropland, serves as an example *par excellence* of indirect land use change, given the pace of land cover change within the area.

Conceptually, I draw from migration theories to understand the movement of capital resources. I situate Sjaastad's neoclassical theory of labor mobility within the context of the rent

or location based economic landscape associated with von Thünen to suggest that the market dynamics that continually reshape an economic landscape also paint a dynamic canvas of opportunity costs and migration incentives. These incentives act to both distribute and redistribute not only land uses, but also the skills and capital essential to rural production.

At its core, this dissertation seeks to clarify how the globalization of the Amazon and the soybean expansion of the past decade have acted both directly and indirectly to push back forest cover and pull in capital. I approach the problem through a mixed method, multi scale approach that combines field work with an innovative spatial econometric model. The results suggest a positive and significant linkage between the expansion of soybean production across Brazil and deforestation in the Amazon. The field level dynamics that underlie this linkage are, evidently, driven by the relocation of skills and capital, with farmers and ranchers from consolidated agricultural and pastoral regions seeking to maximize their utility by acquiring larger parcels in the Amazon. The dissertation provides evidence to suggest that land use change occurs upon the transfer of land between owners of different skill sets, and that former landowners relocate their production strategies to new locations upon displacement from their former properties.

The research is expected to contribute to the broader discussion of land use and land policy, and on the relationships between land use and global markets. It has clearly connected land use to migration patterns, and has done so by situating migration within the context of a globalizing economy, and one which is rapidly incorporating the Amazon into its midst.

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PROLOGUE

Here at least
we shall be free; the Almighty hath not built
Here for his envy, will not drive us hence:
Here we may reign secure, and in my choice
to reign is worth ambition though in Hell:
Better to reign in Hell, than serve in Heaven.

Inferno (lines 258-263)
Dante

Poor men want to be rich
Rich men want to be kings
And a king ain't satisfied until he rules everything

"Badlands"
Bruce Springsteen

August 2008, BR-163.

Somewhere south of Santarém, Brazil's Federal Highway Number BR-163 reverts to little more than a daring channel of dusty velocity and fast approaching obstacles, a dirt highway that parts a sea of green. To our front, a mist of lifted airborne sand, the remnants of the soils that in a previous generation provided the foundations to the mighty Amazon forest, obscures their provocateur. From our perspective the cloud is yet another obstacle to BR-163, an obstacle that, just as with the sand traps and the log bridges that we have already overcome, constitutes only another chapter in our southbound journey. Several times we pull close to the vehicle ahead with an intention to pass, but we are repeatedly stymied by the natural and numerous impediments that appear fast and close from behind the opaque wall of dust. At some point, however, we will have to cross our fingers and accelerate blindly into this unknown. Though fully aware that an unseen rut, any washed out bridge, a sudden swerve by the driver ahead, or perhaps most dangerous of all, a rare but absolutely undetectable pickup coming headstrong on its own barreling journey northward would immediately spell our doom, we are determined to push ahead. Passing clouds of dust is a task we have completed before, and one which we will have to repeat dozens of times on this journey. As always, pass we must, as to remain in the wake of this rust colored inferno is impossible. To remain behind would mean not only slowing our progress, but also remaining in the same choking mist that has forced our windows closed, sealing us within this sweaty heat of our vehicle. So onward we must go, and we steel ourselves for the nervous moment of acceleration.

With pauses in our breath and in the beats of our hearts, the accelerator is pressed hard and our Mitsubishi pickup lurches ahead. Seconds later, we are closing on the cloud and passing that dangerous point of no return. The hulking form of a fuel truck emerges and our tires spin faster as our truck edges to the left in an intensified shower of red earth. The truck driver, now only a few feet to our right, finally detects our presence, slows and moves, if only slightly, to the right in recognition of our attempt. And in moments he will exist only within the lesser than life stature of our 4x6" mirrors, continuing his own weaving course through the rutted decay of BR-163. And indeed, a minute later the fuel truck is well in our wake; and we are quenching our thirst for fresh air, vigorously drawing down our windows with the dirty plastic knobs that have bruised our knees for the past hours, bumping our legs with each bustle and sway of our pickup. And the journey continues.

We are left once more to breathe dust free air and to absorb the magnificence of the big sky of the expansive Amazon range, a panorama that proudly reassumes its role of rolling past our windows. Now well south of Santarém, we are in search of recently arriving farmers and the supposedly emerging agricultural fields located here, in the heart of the Amazon.

The refreshment of the early day, however, is soon replaced by the acidic pungency of smoke and cinder. The char has become difficult to escape, and joins us as an uninvited and unshakable companion, one which will remain with us for the last leg of our journey to Progresso. Five hours later we arrive to Morães de Almeida, the launching point of the prospectors' (or so-called, "golden") highway, home to dozens of rustic saws, each methodically working to consume and process the region's seemingly inexhaustible wealth of timber. As we leave Morães, the green that has surrounded much of our earlier drive southward is, in many places, being consumed in conflagrating hillsides, engulfed in flames of diverse heights and intensities. Elsewhere, the after effects are evident, with pastures and Nellore cattle slowly grazing for grass in cemeteries of charred *Castanha* trees, and the rotting hulks and stumps that now lay prone alongside these monuments to the Amazon.   It is an inferno of destruction and economic progress, and the smoke chokes the otherwise pristine Amazon skies. I enjoin the driver to slow and come to a halt, to capture a scene on film, an unforgettable sight of old growth forests being condemned to death by fire. Three years later I would recognize the same hillside, no dotted with cattle and the gray hulks left behind after the burn.

The smoke, perhaps more than any other attribute of the Amazon aside from the ubiquitous cattle dotting the green pastures, dominates the now largely denuded landscape. The smoke is so thick that the flights into this tiny and exceedingly remote Novo Progresso were canceled on its account. In Novo Progresso we see twenty bustling blocks of commerce and residential, and a forest rapidly receding outward from its core of mining and ranching constituents. Choked by smoke, littered with agents purchasing gold from prospectors paid not in dollars but from the cuts of their claims, and polluted by the screaming whining and hawing of saws and diesel generators, the city suggests a sinister character. It is a frontier town, an opera of the Amazon and those who have colonized it. It is a swirling refuge of the poetry of destruction and dreams, of the marginalized, of the bold, and of the forgotten. And for those who have built this cacophony of violence and opportunity, its dystopia represents not only independence, but dreams and disease, risks and reward, opportunity and opposition, and now, for many, home.

My first meetings in Progresso confirm inwardly what outwardly the town is screaming. At the rural producers' association I am warned rather than welcomed. NGOs, I am told by the President, aptly known by the name of a legendary king of the Hellas, will never be allowed in Novo Progresso, not during *his* lifetime; foreigners and journalists are never to be trusted; I do my best to convince the small but ruthless individual on the other side of the desk before me of my innocence; no, I am not an NGO; it hardly matters I am told; in this small town the activities of those arriving from outside, including myself, must be watched. They have been before, and will be in the future. Those who once came to photograph passing trucks, each laden with timber destined perhaps for Europe or the East, one story went, found it difficult to find lodging in the city's few hotels, let alone fuel for their journey back to Santarém. Be careful that you are not misrepresenting yourself, and beware of misrepresenting your intentions here. There is no room for environmentalists, he says, as we draw the meeting to a close. Were it up to him, all environmentalists would be given the forest and left to their own devices. Surely they will tear down the precious canopies that they claim to protect. Surely, they will draw blood from the hearts of the forest's inhabitants; for if not they will surely perish under the looming swords of starvation, disease, and exposure. Or, still better yet, he concludes, would be both; one foot before the other, all in due time.

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CHAPTER I

INTRODUCTION

1.1 Biorhythms, Beef, and Beans in the Amazon

The Amazon basin encompasses seven million square kilometers of South America's interior. All told, it stretches over parts of eight sovereign nations. More than five million square kilometers of the basin is tropical forest, sixty percent of which is located in Brazil. As the world's greatest tropical forest reserve, the Amazon is an essential cog in the maintenance of the earth's tenuous environmental balances. The forest also serves as an enormous sink for atmospheric carbon, much of which is contained in its above ground biomass. Preserving carbon sequestered in the Amazon has become a focal point in efforts to mitigate global carbon emissions, given that researchers have identified tropical deforestation as a principal source of greenhouse gas emissions (Parry et al. 2007).

During the past several decades ranchers and farmers succeeded in clearing many of the most accessible and less dense forests in the transitional and peripheral regions of Brazil's Amazon Biome. As a result, deforestation during the coming years will likely incur denser strands of tropical forest cover than those cleared previously. Thus even as deforestation rates fall, the total carbon emissions derived from deforestation may not, heightening the present need to control forest conversions (Galford et al. 2011, Galford et al. 2010).

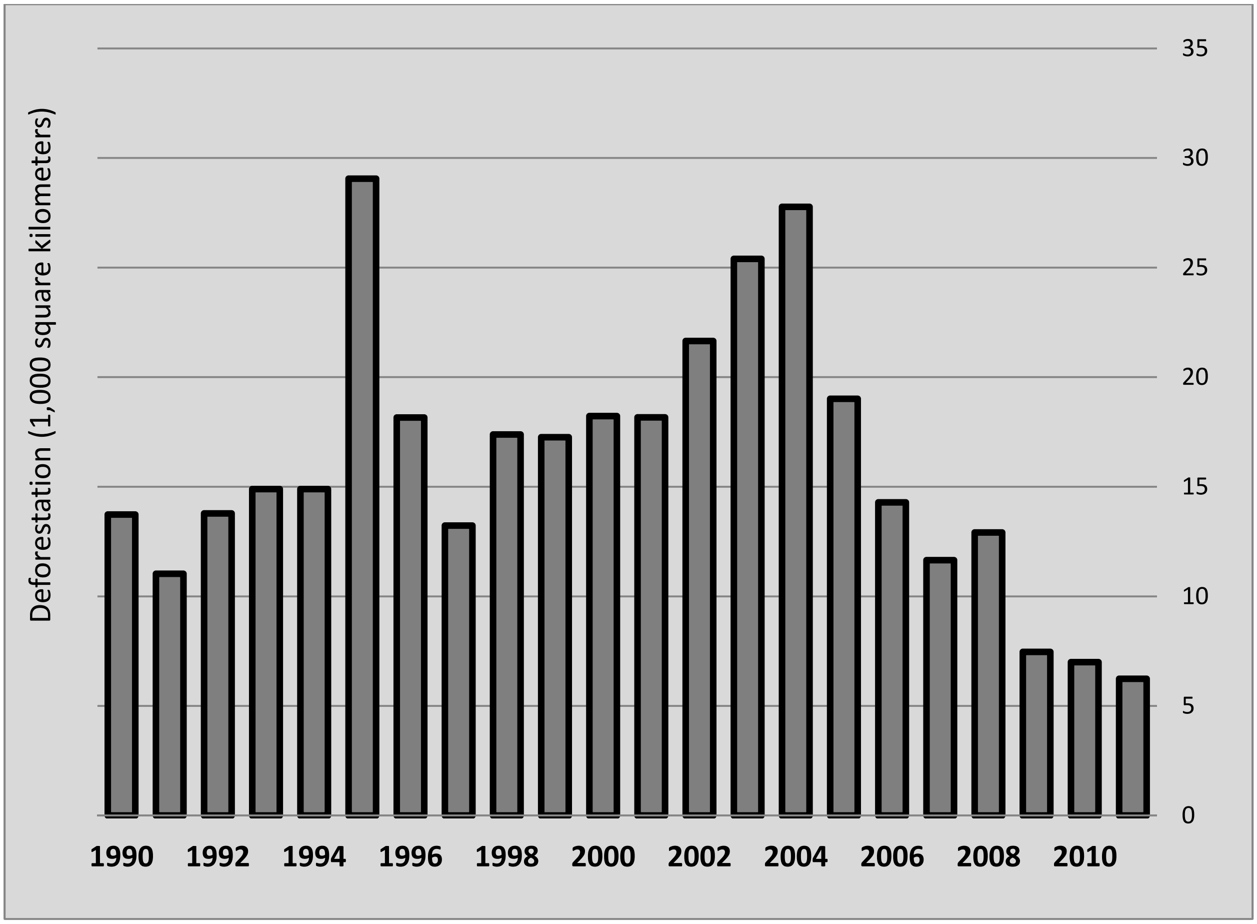

Figure 1.1
Deforestation in the Brazilian Amazon, 1990-2010

(source: INPE 2011)

Tropical deforestation in the Amazon reached a peak during the middle of the last decade, when annual forest loss in this region approached 30,000square kilometers per year (figure 1). The loss of the forest during this period was of such a magnitude that from 2000 to 2005 emissions derived from Amazon deforestation surpassed all fossil fuel emissions in Brazil. In fact, during this period, emissions derived from deforestation in one state, Mato Grosso, surpassed the fossil fuels emitted from all of Brazil (Galford et al. 2011). That deforestation mitigation entails the foregoing of potential future benefits rather than the sacrificing of present day lifestyle habits may make such an effort potentially more politically palatable. In any case, international and national voices have pointed to the global implications of continued forest loss in the Amazon, and have taken steps to reduce its occurrence (Nepstad et al. 2009).

As a source of uncountable biodiversity, Amazon researchers have also come to recognize the value that lies under or within its canopies (Meyers 1980). The region is home to some of the highest concentrations of plant, fish, insect, mammal, and bird diversity found on earth; and compounds from the Amazon forest have contributed to the development of western pharmaceuticals and forest products such as latex and *açai*. Additionally, societies across the globe have found intrinsic values in maintaining forest cover and, by extension, those that dwell below or within its canopies and in its waters, from the pink hued dolphins of the western Amazon to the colorful feathers of the abundant macaws and toucans, to fascinating exemplars of vegetative and insect life.

Maintaining biodiversity and sequestering carbon go hand in hand. And while the means and locations by which to achieve these goals vary, the general principal of keeping forests standing as they are achieves both. Preserving biodiversity requires the preservation of standing forests, and hence the preservation of the same carbon sinks deemed so essential to the global environment. Consequently, maintaining forest cover has been viewed as an essential front for multiple environmental efforts, and much attention has been focused in recent years on documenting forest loss, identifying its proximate and underlying drivers, and orchestrating policy responses.

Responses have emerged from both within Brazil and internationally. Initiatives such as the Reducing Emissions from Deforestation and Forest Degradation (REDD) program and the Soy Moratorium, for example, both designed to reduce deforestation, were built partly through the influence of consumers and advocacy groups in Europe and the United States (Angelsen et al. 2009). Within Brazil new parks were established via the Amazon Region Protected Areas Program (ARPA) and new regulations on deforestation have been added at the same time as existing ones are increasingly enforced (Soares-Filho et al. 2008). Nevertheless, the success of these initiatives has been uneven, owing in part to the spatial and temporal variation in economic incentives and regulations. Deforestation, if slowed, has nonetheless proceeded.

Losses to the Amazon's forest cover thus continue to mount, and annual forest attrition ranges between 6,000 to 30,000 square kilometers per year (INPE 2011). During the past decade, the period of focus in this dissertation, the highest rates of forest loss were recorded between 2002 and 2006, as new market opportunities and economic options for farmers and ranchers in the region created a wave of incentives to capture and clear land. Since 2007, however, rates of forest loss have fallen precipitously. And while this achievement is highly commendable, it must be recognized that rates of forest loss have fallen and risen in cycles in the past; and that despite the recent fall, over the most recent decade more than 170,000 square kilometers of the Amazon forest has been destroyed. To date agents in the Amazon have cleared nearly twenty percent of the Amazon's tropical forests, with the vast majority of these clearings taking place in the peripheral, transitional forests of the Amazon region, or at the margins of the highway network that pierces the biome.

Over the past decades the pressure has increased for the further economic development of the Amazon. And with new pressures, new questions have also emerged (alongside those that have persisted through recent decades) regarding the future of the forest and the basin. Will the forest remain preserved as a wealth of biodiversity and carbon reserve, provisioning benefits to the earth's broader ecological cycles? Will the Amazon serve as a release valve for the poor and socially marginalized? Or will the Amazon be the new bread basket to the world, with its rich plains of forest converted to commodity row crops and grazing areas for cattle? Each of these trajectories will likely play a part in the future of the forest; however, it is increasingly apparent that the gravity that has directed deforestation during the past decades has begun to shift, and that a historical emphasis on understanding local dynamics in livelihoods and social migration within a spatially unbalanced national economy has given way to interest in the large scale provisioning of internationally traded commodities (Walker et al. 2009a, DeFries et al. 2010). How such a transformation will impact the region's forest cover, however, remains to be seen.

When considering forest loss, it must be recognized that deforestation emanates from the hands of those who have chosen upon the forest's felling. To understand why forests are cleared requires first understanding the social and economic forces that shape the decisions of those that affect both forest and agricultural change. Research has revealed much regarding what forces shape these decisions, and have prominently brought considerations of changes in household size, migration, market and road access, inequality in both local and national treasure, and tensions over the control of property into discussions of both deforestation and agricultural change (Young et al. 2006, Keys and McConnell 2005). Many of these drivers will be discussed in greater detail in Chapter III. The focus of this dissertation, however, is on a driver of deforestation that has only recently emerged in academic discussions of land use and land use change, namely the so-called indirect effects, or where land use change in one region acts to reshape incentives in other, potentially distant locations.

As producers and consumers are increasingly connected the world over, what happens in one place may carry a decisive effect in shaping behaviors and actions in other locations. In Brazil concerns that agricultural expansions in the south and in the transitional forests at the periphery of the Amazon is driving deforestation in the basin has assumed an increasingly prominent role at the forefront of discussions of environmental change. These broader spatial and economic linkages, referred to here as indirect effects or indirect land use change (ILUC), comprise the principal focus of this dissertation. This dissertation assumes its own place in these discussions, adding to the topic through a clarification of its conceptual processes and providing both field level and regional scale evidence of its impacts.

1.2 Land Use Change and its Indirect Impacts

For a broad spectrum of policy makers, environmentalists, and academic researchers, indirect land use change has emerged as a topic of particular interest. This interest stems from work by both agricultural economists and researchers within the land change science community, particularly as it has concerned events in Amazonia. From 2008, suggestions that subsidies, mandates, and tariffs for ethanol production were diverting American croplands to biofuel production, and thus creating new agricultural regions abroad to sustain food supplies, gave light to the original concerns over ILUC (Babcock 2009a, Kretschmer and Peterson 2010, Swinton et al. 2011, Fargione et al. 2008, Searchinger et al. 2008, Hertel et al. 2010b, Birur, Hertel and Tyner 2010, Keeney and Hertel 2009). If ethanol policies (designed to reduce fossil fuel emissions) were indirectly resulting in new emissions through clearings of natural land covers elsewhere, then any benefit to these expensive mandates could potentially be minimized, nullified, or even rendered negative. To fully understand the costs and benefits of these programs, a better accounting of the true impacts of biofuel production would be needed, preferably one which could account for the spatial externalities associated with land use change.

Within the land change science community, researchers have also begun to consider how land use in one region influences how land is used in other, potentially distant regions (Walker 2001, Walker and Solecki 2004), particularly with regard to work in the Amazon (Barona et al. 2010, Richards 2012, Arima et al. 2011, Lapola et al. 2010, Walker et al. 2009b). Here research has indicated that, particularly with respect to the case of Brazilian sugarcane and soybean production, while crops may impart an impact directly on the forest, their indirect impacts may nonetheless stand more significant.

Conceptually, policy issues over ILUC begin with the reality that land is a limited resource; and both food and fuel crops (such as soybeans and corn) require large tracts of land for production. If farmers and policy makers are to increase production to meet both new and existing demands for fuels and food commodities, they will likely do so through the conversion of more extensive production strategies or non-agricultural land covers (Lubowski, Plantinga and Stavins 2008, Walker 2001). For economists concerned with the environment, the prospect that new agricultural lands might come at the expense of forest cover raises questions over the long term sustainability of biofuels as a viable energy option.

Economists founded much of their initial work on ILUC on general or partial equilibrium models. New demand for crops for biofuel production would increase the price of agricultural produce which, in turn, would incentive farmers to bring new lands into production. Searchinger, et al. (2008), for example, estimated that increasing US ethanol production to fift-six billion liters would raise prices for corn and soybeans forty and twenty percent respectively, leading to the conversion of 1.8 million hectares of additional land to cropland. Assuming that some of the new farmland currently holds stores of carbon, these conversions could effectively offset any carbon savings attained through a switch from fossil fuel to biofuel consumption.

The debate regarding ILUC has become particularly contentious with the adoption of the Renewable Fuel Standard (RFS) by the United States Congress and the Low Carbon Fuel Standard (LCFS) by the California Air and Resource Board (CARB). Both of these policies are designed to include greenhouse gases derived from all stages of production, including those incurred by clearing lands to produce fuel crops in the accounting process. Whether (and how) policy makers should incorporate potential cropland conversions into cost-benefit considerations, however, has been fraught with controversy (Simmons and others 2008, Simmons and others 2009), as accounting for ILUC effects would diminish or negate the potential carbon savings associated with biofuel production in the American Midwest. Economists have also called attention to the uncertainty in accounting for spatially diffusive causality, drawing additional criticism to suggestions of ILUC (Gnansounou et al. 2008, Babcock 2009b, Babcock 2009a, Hertel et al. 2010a, Tyner et al. 2010a). To some extent, the problem of space and geography in determining the spatial channels of indirect land use change has been addressed through the application of multi-sector, multi-region general equilibrium models such as GTAP (Kretschmer and Peterson 2010, Tyner et al. 2010a, Hertel et al. 2010b, Birur et al. 2010, Keeney and Hertel 2009). However, researchers have conducted most of these efforts at the global scale using price equilibriums and effects are determined at the national scale. This dissertation, in contrast, focuses exclusively on the internal effects of agricultural expansion. A fundamental thesis here, which is generally in contrast to the ILUC literature, is that the expansion of cropland in Brazil may be leading, indirectly, to an increase (as opposed to a decrease) in pasture areas.

This dissertation thus aims to address the region-scale, spatial uncertainty and spatial impacts of agricultural expansion by focusing on land use issues as they cascade across a regional landscape. Here, I examine an area of the world where land use change is occurring rapidly and where ILUC is likely to be present and most discernible, namely in the southern forests of the Amazon Basin. That Brazil (and the Brazilian Amazon in particular) has regularly been cited as a potential point of impact for the indirect effects associated with biofuel production in the US also makes the region highly attractive as a case study for this analysis.

It is essential at this point to note that in Brazil the land use system places cattle pastures and ranching activities in the most marginal production areas, and most of the clearings perpetuated are done with the intention to open new pastures, not agricultural lands. This system tends to position agricultural lands, in contrast, in comparatively less marginal regions, and closer to existing networks of the support industries that are essential to the production of commodity crops. Consequently, direct impacts of cropland expansion on the forest, when compared to those of ranching, are minimal (if nonetheless still significant). However, studies have linked the expansion of soybean production to direct losses in forest cover, particularly in the transitional forests at the southern fringes of the basin and in the *cerrado*, or within the vicinity of existing redoubts of agricultural production, though much of this work has focused on events occurring between 2000 and 2005, or at the height of the soy boom and prior to alarms sounded by environmental groups concerned with their expansion (Galford et al. 2008, Morton et al. 2006, Brown et al. 2005). More recent analyses have suggested a trend towards the intensification of soybean production and away from direct incursions of cropland into the forest in regions of the Amazon (Macedo et al. 2012). Thus both presently and previously, in comparison to cattle ranching, the role of agriculture as a principal and direct driver of deforestation is quite small, even in Mato Grosso, Brazil's leading agricultural state.

In this dissertation I suggest that the impact of expanding croplands may still loom large, only not through the felling of forests, but through the displacement of established pastures and the resources once allocated to production, and to land appreciation in rural areas. This suggestion that the expansion of soybean production has driven an expanding cattle frontier indirectly has already been put forth by studies strongly indicative of spatial linkages between the agricultural and cattle frontiers and losses in forest cover (Lapola et al. 2010, Arima et al. 2011, Barona et al. 2010, Richards 2012, Walker et al. 2009b).[1] However, I build on these studies by formalizing an investment effect as a driver of indirect land use change, and suggest that land use changes occurring in regions distant from the Amazon may still impart significant impacts on the region's forest cover. I designed this dissertation to consider this hypothesis, and to provide new insight into the indirect effects of land use change. I reconsider the movement of sector-fixed skills and capital as a component of land use change, and incorporate an innovative, national scale empirical model that ties together land use changes.

1.3 Problem Statement and Research Objectives

Growing demand for both meat and processed food, combined with the diversion of existing croplands for biofuel production, will heighten pressure for the creation of new agricultural lands in the coming decades (FAO 2010). Globally, unused lands suitable for agriculture are in limited supply; and with much of those that area available being located in South America, and in Brazil in particular, Brazil is likely to play an increasingly important role as a global supplier of agricultural commodities (Shean 2003). Already, over the past decade, Brazil has transformed itself into a key supplier of meat and soybeans. Brazil now vies with the US as the largest exporter of soybeans and has overtaken Australia as the world's largest

[1] Here I conceptualize the frontier as an point of transition between one land use and another. In this case I suggest that the spatial location of the advance of agricultural production is tied to the spatial location of areas where ranching advances on subsistence farming or uncultivated wilderness. I describe and define the frontier more fully in Chapter IV.

exporter by volume of beef products; and with land on which to continue to expand production, the nation appears poised to occupy a still more important role. However, concerns over the environmental implications of creating new croplands and pastures in Brazil and in the Brazilian Amazon, a region of high environmental value, persist; and questions remain over the extent to which an expansion of soybean production or pasture in the region may lead to added deforestation.

As described in the previous section, much of the uncertainty over the environmental impacts of expanding cropland production in Brazil stems not only from the difficulty of qualifying the reasons underlying an individual's decision to clear no land, but also from obstacles related to measuring the diffusive spatial effects associated with land use change. The purpose of this dissertation is to clarify the extent to which Amazon deforestation is tied indirectly to the growth of cropland in Brazil, and to provide a framework by which to better estimate these spatial impacts. Specifically, this dissertation is designed to address the indirect impacts of added soybean production in Brazil, both theoretically and empirically, and through ethnographic field work designed to capture information on migration incentives for skilled agricultural and ranching labor.

The multi-scale, mixed methods approach employed in this research is oriented toward two principal objectives. The **first** objective is to provide an empirical estimation of the indirect impacts associated with the growth in area dedicated to soybean production. To capture the indirect effect derived from the expansion of soybean area I build on the innovative application of spatial econometrics employed by Arima, et al. (2011) by weighing the effect of changes in potentially distant areas of planted soybeans on deforestation in Amazon counties according to access. The **second** objective is to provide field level evidence, based on considerations of rancher and farmer movements and investment patterns, to better assess and verify the mechanisms and role of human and financial migration as a fundamental component in indirect land use change. I conduct much of this ethnographic work at the regional scale, focusing on the Santarém-Cuiabá corridor in northern Mato Grosso and western Pará States.

1.4 Principal Objectives and Hypotheses

The principal research objectives and their associated hypotheses can be stated as:

Objective 1: *To provide an empirical estimation of the indirect impacts derived from the expansion of cropland in Brazil.*

- **H1.1:** The expansion of agricultural commodities production in Brazil has resulted in indirect forest loss.
- **H1.2:** ILUC is measurable and can be estimated

Objective 2*: To measure and verify the processes driving regional ILUC through field level research.*

- **H2.1:** Deforestation in the Amazon is affected by land use changes occurring elsewhere in Brazil.
- **H2.2:** Farmers and ranchers who relocate their operation do so to amplify their access to land.
- **H2.3:** The decision of where to relocate an operation is a function of distance and difference in land prices.
- **H2.4:** Land use change occurs with changes in control over land, indicating that a change in skills and capital is an essential element in the land use change process.
- **H2.5:** New ranches have been reconstituted in areas of recent deforestation from pre-existing locations now used for soybean cultivation.
- **H2.6:** Indirect land use change in the Amazon occurs with the displacement and relocation of skills and capital to the frontier.

1.5 Dissertation Outline

I begin this dissertation with a review of the political and economic policies that have shaped the development of the Amazon. In **Chapter II**, I thus consider the transformation from the old republic, where the Amazon was viewed as looming with untapped potential, to the military regime that sought to occupy the region, with capital first, but then with populist sentiments, and finally, to the market oriented economy of today. In particular, in this chapter I highlight the transition to the democratic government in the 1980s, the broad shift in economic policy toward market liberalization and a focus on the production of export crops. Understanding these shifts, and the transition from a frontier driven by social and financial marginalization and crony capitalism in the 1970s and 1980s to one driven by market opportunities in this new millennium is a key to understanding the changing drivers underlying forest loss in the Amazon.

In **Chapter III** I consider the present day drivers of deforestation in the Amazon, based from recent and past literature, with a particular focus on the evolution of the cattle and soybean sectors in the region. The chapter begins by considering the economic transformation of the Amazon from a region viewed primarily as a source for extractive goods to one prized for its agricultural and pastoral potential. I discuss the relationships between agriculture, ranching and deforestation and survey past work on land use change in the region.

Chapter IV provides the theoretical foundations to the dissertation. After drawing on the foundational works of Ricardo and von Thünen, and from more recent work on household models, political ecology, and land economics, I develop the location-utility model that serves as the basis to this research. This model conceptualizes the displacement process as a function of individual or agent based decisions occurring within a broader structure of economic incentives.

The farmer or rancher is viewed here as a mobile embodiment of capital, whose relocation results in the spatial redistribution of capital from capital abundant, land scarce areas to where land is relatively abundant and capital is scarce. The process occurs within an incentive structure built upon a dynamic landscape of rents, land prices, and access. I take care to differentiate between a supply adjustment effect and an investment effect, two components that I conceptualize as comprising the underlying mechanics of indirect land use change.

I address the first objective, namely the provisioning of an estimation of indirect land use change associated with soybean production in the Amazon, in **Chapter V**. I begin with a review of econometric and spatial econometric models of deforestation, and suggest that the indirect effects associated with land use change may bias the results of non-spatial econometric models. I capture the indirect effect by developing a spatial durbin model (SDM) capable of weighting the growth in soybean production by transportation costs. After a description of the variables and the weighting structures used in the model, I provide a summary of the results, followed by a brief set of concluding remarks and discussion.

This leads immediately to **Chapter VI**, where I present the results from field work conducted in the BR-163 region of western Pará and northern Mato Grosso States. The chapter first considers a contextual approach and provides a description of the region and its settlement and development over the past decades. It then proceeds to situate the conceptual outline of the location utility model and the estimated indirect impacts while recognizing the region's political economic and geographic context of region. I aimed the survey at better understanding the movement of skills and migrants' origin, as well as the motivations underlying the decision to buy or sell of both the purchaser and seller of properties in the Amazon. The chapter considers the survey responses and provides descriptive maps of the resource flows across the region.

The broader conclusions of this dissertation are presented in **Chapter VII**, where each of the objectives and hypotheses are listed and explicitly considered. I draw from the results of Chapters V and VI to provide recommendations for Amazon development policy, and highlight conceptual advancements that may be of interest for future research on both ILUC and studies of land use change in the Amazon.

This dissertation, through the sum of its chapters, provides a mixed methods approach to understanding the drivers of forest loss in the twenty-first century. It incorporates both field research to better understand the farm level processes underlying ILUC and the statistical estimations of their broader outcomes. I designed the dissertation to provide an overview of the broader changes occurring across the Amazon Basin as markets and demand for food commodities increasingly draw the region into the global economy. At its base lies the argument that the penetration of global markets into South America's interior has imparted its impacts broadly across the region, with its effects distributed both directly and indirectly across a landscape.

The focus of this dissertation on soybeans and cattle is not to devalue the effects of other patterns and processes occurring across the Amazon, but rather it is to highlight the recent emergence of a new phenomenon of land cover change in the region. Soybean production here has transformed the region, leading to both prosperity and the erasure of biodiversity, with the vast majority of its expansion occurring only in the past two decades. Cattle ranching is by no means only a recent phenomenon in the Amazon; but the ways by which it has manifested itself in the past decade little resembles the grand ranches that graced the Amazon in the early days after the opening of the frontier in the 1970s. The opening of the Amazon to new markets both abroad and internally, whether through the eradication or control of disease, the removal of tariffs, or currency manipulations, has rendered the area a fertile ground for agricultural and beef production and redefined its landscape. This dissertation will directly engage with the new realities of land use and land change in the region and seek to contribute to the growing body of literature that aims at better understanding and comprehending the new and complex array of forces that now act to shape anthropogenic changes in the Amazon. The story begins in the following chapter with considerations of the structural changes to the broader political economy of Brazil and the Amazon stage.

CHAPTER II

THE POLITICAL ECONOMY OF THE AMAZON: FROM EXPLORATION TO EXPLOITATION

The Amazon Basin has a long history of drawing the adventurous, the bold, and the daring into its midst. Those that have come to plant soybeans or who arrive to open new lands on which to graze cattle or escape the pressures of economic exploitation elsewhere in Brazil comprises yet another chapter in this succession of characters and adventurers seeking fortune in the region. In recent years the result of their arrival, the growth of Brazil's cattle and soybean sectors, has caught the attention of the world. However, I recognize that the recent expansion of both soybeans and cattle is inextricably linked to the series of booms and busts which preceded it, and to decades of efforts to cultivate a stable and self-sustaining Amazon economy. In this chapter I situate the economic development of the past decade within an institutional and economic landscape defined, in part, by decisions made under the Brazilian military regime (1964-1985) and later, during the transition to democracy and away from the era of import substitution industrialization. These periods occupied a critical role in rendering Brazil's Amazon states sufficiently fertile to agriculturally driven economic development. This chapter follows these political and policy decisions, and recognizes their roles in shaping its present day economy.

2.1 Early Adventures in Exploration and Exploitation

Many have come to the Amazon Basin in search of refuge. Others have come in search of its unique riches, or the glory of exploration; most recently, many have come in search of the ample land and fertile soils with which to satiate the appetites of distant kingdoms. Seeking wealth from the Amazon is thus by no means a recent phenomenon, and today's economic boom might better be viewed not as a response to any single shift in policy, but rather as the most recent appendix to an already lengthy timeline of exploration and exploitation.

Of the long lineage of outsiders who have sought their fortunes in the Amazon, Francisco de Orellena and his crew were likely the first of European descent. Navigating the Amazon from Ecuador to the Atlantic, his expedition provided the region's earliest descriptions, including images of cities and skirmishes with riverside warriors during their 1542 journey. The Portuguese commenced their colonization of Brazil and the Amazon shortly thereafter, with the establishment of settlements along the Atlantic coast and at Belém, near the mouth of the river. The arrival of the Portuguese set in motion an ongoing process of dispelling fugitive slaves, defeated rebels, and displaced indigenous nations into the continent's interior forests.

In the late 19th century, many more would penetrate the inner forests of the Amazon Basin, only increasingly they now came not in escape from social or economic marginalization, but in search of the region's natural wealth, much of it embodied at that time in the form of natural latex. Over the ensuing years, *seringueiras*,[2] many from Brazil's northeast, moved into the inner tributaries of the Amazon River to tap the rubber laden *heavea* and *caucho* trees scattered across the basin (Barham and Coomes 1996, Weinstein 1983). While the boom in rubber would prove to be only temporary, it nonetheless raised the possibility that the Amazon Basin, long a marginal jungle of forest, disease, and unexplored waterways, might hold the potential for economic gain.

[2] The workers responsible for tapping wild rubber trees.

Indeed, the rubber boom placed the region within the public conscience, raised cities, and set off new attempts to explore, map and one day exploit the basin. Marshall Cândido Rondon, a Brazilian military officer and noted explorer, gained national recognition during this period for his efforts to map the lost waterways of the region, even playing host to Theodore Roosevelt during an exploratory trip down a forgotten river in the central part of what would become Rondônia State. Perhaps not surprisingly, Rondon encountered not only indigenous tribes living in the uncharted territories of the Amazon, but also posts of rubber tappers who had pushed as far as possible into the inner reaches of the basin.

Yet despite the increased activity, the Amazon forests withstood the rubber boom, remaining largely intact into the middle of the 20th century. However, these forests, perhaps once viewed as impregnable, have since belied their vulnerability, succumbing to the distinct pressures of economic development, emanating first from elsewhere in Brazil, and now also from beyond.

2.2 Operation Amazonia

Broad scale deforestation of the present magnitude emerged in the Brazilian Amazon only over the past fifty years, or since a significant push was made by Brazil's military government to incorporate the region into Brazil's coastal-centric economy (Schmink and Wood 1992, Mahar 1979). Though as early as the 1940s the government was envisioning plans for the Brazilian Amazon that amounted to more than the mere extraction of unprocessed wealth, much of the region remained unsettled and perhaps, impenetrable into the 1960s. Indeed, with no land link to the south, Brazil's Amazon region was effectively separated from Brazil's core economic zones in São Paulo State and along its southeastern coast. To incorporate the region into the rest of the nation economically, politically, and socially, steps needed to be taken.

The process of incorporating of Brazil's interior into its coastal-centric political economy began in earnest in the latter half of the 20th century with the spectacular relocation of the federal capital from cosmopolitan Rio de Janeiro to the wilderness of Goias State. In the late 1950s Brazil carved out the City of Brasilia in the form of an indigenous warrior shooting his arrow into the continent's inner forests and toward the Amazon River itself. The new city was a metaphor for the new frontier and a symbol of the nation's intention to occupy its interior. Subsequent governments continued the process, and the frontier was progressively extended northward. The so-called "jaguar highway," or federal highway BR-010, cut through thousands of kilometers of largely unsettled territory, crossed innumerable streams, creeks, swamps, and rivers, and stitched together two disparate ends of the country. By the early 1960s Belém and the Amazon River were for the first time linked by land to the remainder of the nation, and a frontier was opened along the eastern Amazon Basin. The government's successful completion of BR-010 would serve as a template for future mega-infrastructure projects.

Ecologically and socially, the denouement of BR-010, just as with many other road building projects present, past and planned, remains a point of contention. Deforestation in northern Tocantins State and the South of Pará, areas traversed by the new road, was rapid and in many cases nearly complete in its extent. Social conflict, including seeds of socialist revolution in the Araguaia valley, a populist takeover of some of the richest gold deposits ever found at Serra Pelada, and a massacre of protestors associated with Marxist-landless movements, have also marked much of the region through which BR-010 passed. Even today, some forty years after its completion, the region remains among the most violent in the nation (Simmons et al. 2007, Aldrich et al. 2011, Walker et al. 2011b). In terms of opening a new transport corridor and incorporating a new frontier into the national economy, however, BR-010 was highly successful.

It was also the first of Brazil's great road projects to be successfully completed, and with settlement and economic development in the region occurring rapidly, a model was in place for future development initiatives.

In 1964, Brazil's Second Republic (1946-1964) was overthrown by a military coup, opening the way for a series of military governments to preside over the nation's development. Under the autocratic military regimes that dominated the ensuing decades, a new focus was brought to developing the Amazon, this time under the guise of national security. At the time the region, which encompassed nearly one half of the nation's territory, was sparsely occupied and included unguarded borders with seven foreign nations. It's perceived vulnerability to foreign interests led the nation's generals to take a greater interesting in developing the region in the name of nationalism and security (Foresta 1982). With whispers of supposed international interest in the Brazilian Amazon percolating, including rumors that American and European interests were aiming to capture the natural resources of the Amazon under the guise of establishing an international ecological reserve, action was quickly taken. The result was *Operation Amazonia*, a military blueprint for the invasion, development and colonization of the basin.

Operation Amazonia combined public investment in infrastructure and highways with fiscal incentives to draw private capital from Brazil's industrial south into the north. The operation officially commenced in October 1966, when President-General Castelo Branco signed decree-law 5.1744, creating lucrative incentives for corporations to invest in the region. Included in the incentive package was an offer to offset up to fifty percent of corporate taxes in return for investments made within the newly created Amazon political entity, the so-called

"Legal Amazon,[3]" for up to 12 years. For projects initiated prior to 1972, tax write offs could be increased up to 100 percent. Despite concerns over national security, the liability exemptions could be claimed for any approved investment project, regardless of investor nationality (Browder 1988, Hecht 1984).

In addition to tax write-offs, many of *Operation Amazonia's* projects received additional subsidies through the Superintendence of Development for the Amazon (Superintendência de Desenvolvimento da Amazônia, SUDAM), which was created in 1966 to direct development funds, some of which included loans from the World Bank and USAID to the Amazon Region (Branford and Glock 1985). In 1966, as a complement to SUDAM, the Bank of Amazonia was created to provide fiscal support for development projects and facilitate the northward flow of capital. Both SUDAM and the Bank of Amazonia replaced holdover institutions from the Getulio Vargas administration of the 1940s, namely the Amazon Regional Development Authority (SPVEA) and the Rubber Credit Bank, both of which were widely viewed as ineffective and riddled with corruption (though to what extent these institutions constituted efficiency improvements remains of some debate). *Operation Amazonia* has largely been decried as a state sanctioned transfer of the nation's wealth to its economic and political elite, it does appear to have been successful in directing the spatial redistribution of private capital from Brazil's industrial south into the Amazon.

Given the complexities of negotiating a potentially cumbersome bureaucracy and an apparent preference for supporting large projects for well funded corporations, few of the nation's small farmers appear to have benefitted from this development plan. In any case, the average area of SUDAM supported ranches was an astonishing 236 square kilometers (Browder

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[3] The Legal Amazon includes the Brazilian States of Acre, Amapá, Amazonas, Mato Grosso, Pará, Roraima, and Tocantins, as well as the western portions of the State of Maranhão.

1988). Yet at the same time, there were few structured colonization programs to redistribute land to the small farmer initiated during the period; from 1966-1968 only six colonization programs were executed in Brazil, totaling to less than 2,000 square kilometers (Santos 1985). During this period contention was emerging over land ownership in the Brazilian Amazon, as riverside dwellers and agricultural migrants arriving from the northeast faced off with the bearers of titles newly minted in São Paulo. In regions in eastern Pará and Mato Grosso, many areas had already been cleared and occupied by small farmers migrating into the region or by the *ribeirinhos* who had occupied the area since earlier economic booms in rubber of Brazil nuts. As the agents of distant landowners moved to claim their properties, police, the national guard, or unsanctioned purveyors of force were often used to settle land disputes (Branford and Glock 1985, Foweraker 1981, Hecht and Cockburn 1989, Aldrich et al. 2011, Schmink and Wood 1992). That *Operation Amazonia* appeared to have been designed chiefly for the region's corporate denizens, however, contributed to rising social tension throughout not only the Brazilian Amazon, but across Brazil.

At the same time as tensions over land ownership were increasing in the Brazilian Amazon, contention was also emerging in the nation's south, where the farming descendants of Italian and German immigrants were squeezed by growing populations, changing economic paradigms, and a dwindling supply of available agricultural land. Earlier in the century these farmers had extended an agricultural frontier westward into the rapidly depleting Atlantic Forest regions of the States of Paraná, Santa Catarina, and Rio Grande do Sul (Margolis 1973, Foweraker 1981). With that frontier now nearly exhausted, and an agricultural economy built on coffee and cotton giving way to more spatially extensive ranching and soybean production, concerns over the future livelihoods of rural workers in Brazil's south also began to emerge. The perception of socialist leanings in the region likely further contributed to the military's wariness of leaving the issue of land distribution unaddressed.

During the 1970s, issues in the nation's poorer northeastern states were also drawing attention. Drought and famine in the region was not only capturing the minds of the rest of the nation, but dispelling migrants southward into Brazil's industrial regions in search of sustenance. The rapid movement of unskilled, rural labor to the nation's core urban centers in São Paulo and Rio de Janeiro was resulting in overcrowded *favelas* and triggering social tensions in these areas. Recognizing the possibility that social tensions carried the potential of national security problems in their own right, the government moved to address the source of both issues, namely a contrived scarcity of land, and do so without challenging the existing inequality of land distribution. To the ruling elite, the unexploited lands of the Amazon Basin were the answer. By carving new frontiers from the nation's interior forests, the military government could avoid pressure for land redistribution while at the same time abating tension from overcrowding in rural areas. To accomplish the task, however, they needed to incorporate the small farmer into the development process. The federal government formalized this policy transformation through the National Integration Program.

2.3 *The National Integration Program*

In 1969, Operation Amazonia was replaced with the National Integration Program (PIN), the military's revised master plan for the Brazilian Amazon. The new development plan would focus on the creation of agricultural colonies, as opposed to the redistribution of land for large ranches for the wealthy or politically connected. Slogans such as "*integrar, para não entregar* “(integrate, to not hand it away) and “a land without people for people without land,” drew people into the region; and onward they came (Foresta 1982).

One of the first initiatives under PIN was the organization of the National Institute for Colonization and Agrarian Reform (INCRA) in 1970, created with a charge to execute forthcoming colonization programs and redistribute land. Before land could be redistributed, however, it needed to be obtained by the government. Given that in many of the most accessible regions of the Amazon the government had already ceded or sold public lands to large projects as part of Operation Amazonia, new frontiers would need to be created. To create these new frontiers, several ambitious roadways were planned or established. This included the Trans-Amazon, an east-west transect cutting across the center of the basin, to the south of the Amazon River; the Cuiabá-Santarem highway, which transected the basin in a north south direction; and BR-364 and BR-317, which skirted the southern forests and led westward towards the Peruvian border. To then ensure the availability of land for distribution to the small farmer, the government issued a decree to capture for its own lands surrounding the proposed highways. Thus in 1971, by Decree-Law 1164, 100km swaths of *terra devoluta*[4] along each side of these new highway corridors were transferred to state ownership, with the intention of repackaging for distribution by INCRA (Schmink and Wood 1992).

The Trans-Amazon Highway, officially BR-230, commences in the State of Paraiba on the eastern Atlantic coast. After crossing several of the poorest states in northeast Brazil it arrives to the edge of the eastern Amazon, where it proceeds across the tropical forests of northern Pará and, eventually, the remote forests of southern Amazonas State. The military government originally planned the Trans-Amazon highway to extend to as far as Tabatinga, on

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[4] *Terra devoluta* refers to lands that have no particular owner and which are not under use for a specific federal, state, or municipal use.

the Colombian border, though it was never completed. Today, the Trans-Amazon now comes to a relatively unspectacular end at the town of Labrea, located on the banks of the relatively minor Amazon tributary but formerly enriching rubber conduit, the Purus River (Walker et al. 2011a). In essence, it was believed that by creating a highway leading from poor areas with poor soils to the Amazon, where soils might be better and where land was comparatively available for colonization, northeasterners they would draw in potential settlers (SUDAM 1976).

If the Trans-Amazon was designed to connect the northeast with the central Amazon, another central element to the PIN initiative, federal highway BR-163, or the Santarém-Cuiabá highway, would accomplish a similar feat for those in Brazil's southern states. In the early 1970s, BR-163 was extended from southern Mato Grosso northward into the center of the southern basin and to the Amazon River itself, at Santarém. Together, BR-163 and the Trans-Amazon were intended to attract hundreds of thousands of families into the region. Small farmers from the northeast would settle in agro-villas and agricultural cities located along the Trans-Amazon, while farmers from the southern states would follow the new highway conduit northward to settle in colonies along BR-163 (SUDAM 1976).

Evidently, migrants' origins and levels of wealth prior to migration played an important role in determining the success of the places that they colonized (Caviglia-Harris, Sills and Mullan 2012, Fearnside 2008, Almeida and Campari 1995). If many of the colonists arriving from the northeast arrived poor and without institutional support, those that arrived from the south benefitted from certain institutional, educational, and financial advantages over their counterparts arriving from the northeast. The existence of relatively strong collective institutions in the south, for example, as well as advantages in wealth and education over their northeastern settler counterparts are believed to have been essential to the rapid advance of the region's newly founded cities and institutions (Jepson, Brannstrom and Filippi 2010b). As noted in Andersen, et al (2002), those counties that received more colonists from wealthier regions of the nation showed steadier and greater economic growth than those that received migrants from poorer regions.

Although federal assistance in infrastructure, education, health facilities, and food procurement was often promised to those that heeded the calls to settle the Amazon, delivery of these services, if it occurred at all, was sparse and remarkably uneven across the basin. Many settlers succumbed to regional afflictions such as malaria and dengue; many more chose not to risk their lives in the Amazon and simply returned. Whereas plans called for one hundred thousand families to be resettled on the Trans Amazon highway by 1975, officially, as few as 7,500 had actually arrived (Browder and Godfrey 1997). And in some places, return rates ranged as high as 50 percent (Santos 1985). Though many of the colonization initiatives in the Amazon fell far short of their official expectations, INCRA estimated that nearly 50,000 colonist families, or about 250,000 individuals, nevertheless made their way into the Amazon between 1964 and 1976 (INCRA 1978).

Operation Amazonia and PIN were only two steps from a growing lineage of Amazon development plans put forth by the Brazilian governments. By 1975 PIN had been succeeded by Polo Amazonia, a new development plan designed to distribute land uses “rationally” and employ meta planning strategies favored by urban planners of the previous decades (SUDAM 1976). For a more complete description of the ins and outs of these policy programs see some of the ample literature on the topic (e.g., Walker, et al 2009). This dissertation, however, will proceed directly to the market reforms instituted upon the return to democracy in the 1980s. For while the military era policies acted to open the Amazon to development and incorporate the region into the national economy, it was the market reforms enacted upon the return to democracy that would open the Amazon to the world.

2.4 Democratization and Market Reform, 1985-1999

The denouement of the Brazilian military regime in 1985 and the transfer of power to the civilian rule of the present day New Republic had widespread impacts on Brazil's political economy, with particularly important implications for its agricultural sector. Embedded within the political transition was a shift in economic priorities from a focus on national security to free markets and integration into the global economy. Thus where the military dictatorship, keenly aware of national security issues, had incentivized the production of food commodities for domestic consumption and import substitution industrialization (ISI), the new democratic government turned toward market liberalization and trade.

Historically, during military era policy makers subscribed to a series of ISI policies, where barriers to trade, fiscal incentives for industry, and high tariffs on imports, particularly on imported manufactured good, were designed to cultivate the domestic industrial sectors (Helfand and Rezende 2004). The policies that they enacted at that same time were crafted to incentivize the production and maintenance of large stocks of food commodities in Brazil, namely rice, coffee, milk, and wheat. Value added taxes on agricultural exports, designed to ensure an abundance of food commodities at home and insulate domestic producers and consumers from external market shocks, for example, also diminished incentives to produce for international markets. For domestic staples such as wheat and coffee, exporters faced export duties as high as 50 percent; for soybeans, an additional 13 percent (Helfand and Rezende 2004). Price supports, import tariffs, and stock purchases of domestic food commodities by the federal government likewise acted to direct production towards domestic markets.

With the reintroduction of democracy to Brazil, many of the ISI policies of the military era were shed in favor of market liberalization, and a series of credit and market reforms were slowly enacted across the nation's broader economic landscape. While many of these reforms were indeed directed toward the agricultural sector itself, reforms aimed at the industrial sector also had fateful, if indirect, impacts on Brazil's agricultural exports (Helfand and Rezende 2004). The impacts were especially powerful in regard to the opening of Brazil's agricultural sector to global export markets, particularly for beef and soybeans. Notable policy reforms that the new democratic government enacted in this period included (a) across the board reduction of nominal tariff rates from 1985 to the late 1990s; (b) the removal of price supports for basic food commodities; (c) the treaty of Asuncion and the development of the Common Market of the Southern Cone (MERCOSUR), in 1991; (d) currency reform and the institution of the Real Plan, in 1994; and (e) the Kandir Law, or the exemption of raw material and semi-manufactured products for export from ICMS value added taxes, in 1996. Combined, this series of reforms proved highly favorable for the Brazilian agricultural sector, particularly, for agricultural exports. Each of these will be briefly discussed.

(a) *Tariff Reductions.* During the ISI period, high tariffs on imported goods protected domestic industries but increased costs of imported inputs essential for large scale agriculture, such as fertilizer and mechanized technology. In the wake of the military period and the rebirth of democracy many of these tariffs were dismantled. From 1989 to 1993, mean tariffs for manufactured goods and primary products fell to less than a third of their value, from 44.4 to 16.6 percent and 31.6 to 9.1 percent, respectively. Tariff rates have since remained relatively low, and have stabilized in the low teens for manufactured goods and around 8-10 percent for primary products (World Bank 2012). Decreased costs for foreign inputs likely contributed to an increase in Brazilian agricultural productivity. From 1990 to 1997, Brazilian productivity increased overall, but particularly in agriculture.

(b) *Minimum Pricing.* Throughout the 1980s the government employed price supports to ensure plentiful stocks of basic food commodities, minimize domestic food costs, and ward off inflation. The Production Finance Agency (Companhia de Financiamento da Producão, CFP) acted to set minimum prices for commonly consumed agricultural goods. Minimum prices, particularly for rice, played an important role in allowing farmers to establish production in remote frontier areas such as northern Mato Grosso (Jepson et al. 2010b). The price supports, aimed at domestically consumed crops, effectively shifted agricultural areas away from the production of crops consumed abroad. The removal of these supports reversed this trend, and negatively affected domestically consumed crops such as rice, wheat, and beans. Statistics on areas planted suggested that many farmers either converted their production to more profitable crops (such as soybeans) or sold their properties those that were willing to do so (IBGE 2012).

(c) *MERCOSUL* In 1991, with the Treaty of Asuncion, the governments of Paraguay, Uruguay, Argentina and Brazil established MERCOSUL, an economic bloc designed to facilitate the movement of goods and services between member states. Free trade forced a realignment of agricultural production across Brazil, as Brazilian farmers now competed directly with the highly developed agricultural sectors in neighboring Argentina and Uruguay (Helfand and Rezende 2004). Arguably, creating MERCOSUL affected no sector in Brazil more than the wheat sector. Wheat production in Brazil declined, and Brazil now imports most of the wheat that it consumes. In the southern states where wheat once reigned, however, soybean production expanded rapidly.

(d) *The Real Plan* The Real Plan was a series of policy maneuvers instituted in 1994 to replace the wildly inflating Brazilian cruzeiro with a more stable currency, the real. In its initial phases, the government established the real as a virtual currency, a move designed to gain consumer confidence in the currency prior to its actual release. The plan proved highly successful in controlling inflation, with annual price increases dropping from 500 percent in June 1994 to only 3.5 percent in June of 1998 (OECD 2005).

The stabilization of the real affected the agricultural sector through several channels. Because land had previously been viewed as a sound investment alternative to unstable markets, market uncertainty had previously led to increased prices for agricultural land. However, this value was derived from land speculation or its use as a means by which to safely store investment capital (rather than for its production capacity). The strengthening of the financial markets and the real in the 1990s removed some of these incentives to land ownership, and contributed to a rapid decrease in land prices in Brazil (Helfand and Rezende 2004, OECD 2005). The resulting low prices in agricultural land allowed the government to expropriate and redistribute more land between 1994 and 2004 than in the 30 preceding years (Helfand and Rezende 2004).

Over the long term, however, the stabilization of the real certainly led to brighter conditions for domestic investments, both from abroad and from within Brazil. And the overvalued real of the late 1990s, maintained initially to ensure the stability of the new currency, created favorable conditions for imports, as tractors and fertilizers essential in increasing worker productivity in agriculture, suddenly became more affordable to Brazil's domestic agricultural sectors.

(e) *ICMS Tax Exemptions* In Brazil taxes on goods and services account for nearly one half the nation's tax burden, much of which is derived from state level ICMS (Tax on the Circulation of Merchandise and Services) tax (OECD 2005).[5] The ICMS tax continues to assume a particularly important role in Brazilian agriculture districts; in Mato Grosso, ICMS taxes, for example, accounted for fifty-seven percent of the state's revenue from 2002 to 2004 (Cursi 2007). For soybeans and beef, ICMS rates range from 6.5 to 13 and 17 percent, depending on the state. Nevertheless, today much of Brazil's soybean and beef output is exempt from ICMS taxes, with primary and semi processed goods destined for export were exempt from ICMS taxes via the Kandir law. Given that Brazil exports approximately ¾ of its soybeans in primary or semi-processed form, the exemption was widely beneficial across the soybean sector. Prior to the Kandir law, ICMS taxes on soybeans averaged thirteen percent on soybeans, eight percent on oil, and eleven percent on soybean meal, inadvertently discouraging domestic processing and encouraging the exportation of soybeans in the raw form (Goldsmith and Hirsch 2006)

[5] Tax on operations relative to the circulation of goods, services, and interstate and intercounty transport and communication (*Imposto sobre Operações relativas à Circulação de Mercadorias e Prestação de Serviços de Transporte Interestadual e Intermunicipal e de Comunicação*)

The reformation period of the late 1980s and early 1990s paved the way for rapid growth in Brazil's agricultural sector. However, these reforms did not affect all aspects of Brazilian agriculture equally. Indeed, the loss of protectionist measures proved harmful to some farmers, particularly rice and wheat producers, who produced crops for the domestic market. As might have been predicted, crop areas dedicated to rice and wheat declined rapidly during the reformation period. Between 1986 and 1996, areas of rice production fell by 23,000 square kilometers, or to forty percent of their previous levels. Wheat declined from 39,000 to 18,000 square kilometers during the same period (Food and Agriculture Organization 2012), with Brazilian produce overtaken by tariff free imports from neighboring MERCOSUL members. Today, the results are evident, with eighty-eight percent of Brazil's wheat supply now entering from Argentina; and seventy-eight percent of its rice crop arriving from either Argentina or Uruguay (OECD 2005). However, if the reforms were detrimental to domestically consumed crops, on the whole, they were exceedingly favorable for producers of crops destined for export markets. Beef, soybeans and their derivatives (including pork and poultry) in particular made significant gains in area and in overall production during the 1990s. It was one final reform, however, namely the devaluation of the real, which triggered the rapid expansion of soybean and pasture production in Brazil, with particularly strong effects in the Brazilian Amazon.

2.5 The Devaluation of the Real and the Brazilian Soybean Boom

The institutional reforms of the 1990s set the stage for rapid agricultural growth. However, it was not until the devaluation of the real (and later, the eradication of foot and mouth disease) that the agricultural and beef sectors would reap the full power of the nation's agricultural potential. When the Brazilian government floated the real for the first time in January of 1999 the currency immediately fell to ½ of its value; it hit its lowest point in 2002, when it bottomed out at 3.90$RS per 1$US. The devaluation of the real acted to effectively double the prices for export commodities, including soybeans, and created a boom for farmers. Thus even as international soybean prices remained stable, or even as they were declining in global markets (as they did for much of the late 1990s and the early 2000s), currency dynamics gave rise to a boom period for Brazil's agricultural exports (Richards et al. 2012).

To illustrate the effect of the currency devaluation on soybean production in Brazil, consider the evolution of soybean prices from 1996 to 2009. From 1997, the average price of soybeans fell from approximately 250 dollars per ton to lows of 150 dollars, where it would remain stable through 2001. Yet during the same period, with the devaluation of the real, prices in the local currency surged higher (Richards et al. 2012).

Table 2.1

Soybean price and 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

From Richards, et al (2012)

As indicated in table 2.1, from 1999 to 2004 soybean prices in Brazilian reals, (normalized to year 2000 currency), effectively increased by 130 percent even as, globally, prices rose only 50 percent (Food and Agriculture Organization 2011a). The rapid increase in prices for soybeans during this period gave rise to what has often been referred to as Brazil's soybean boom, and has been cited as accounting for as much as 30 percent of the expansion of Brazil's soybean area since 1995 (Richards et al. 2012). The impacts on the Amazon are even more acute, where the area supply response was even higher, given the relative availability of land in this region. Richards, et al, for example, tied 43 percent, or approximately 27,000 square kilometers of new croplands in the region to the fall of the real. It is notable that deforestation rates peaked with the boom in export goods in the early 2000s. From 2000-2004, more than 70,000 square kilometers were deforested in the Legal Amazon, the highest three year interval of forest loss seen since 1988, when INPE began closely monitoring forest loss in the Amazon (INPE 2011).

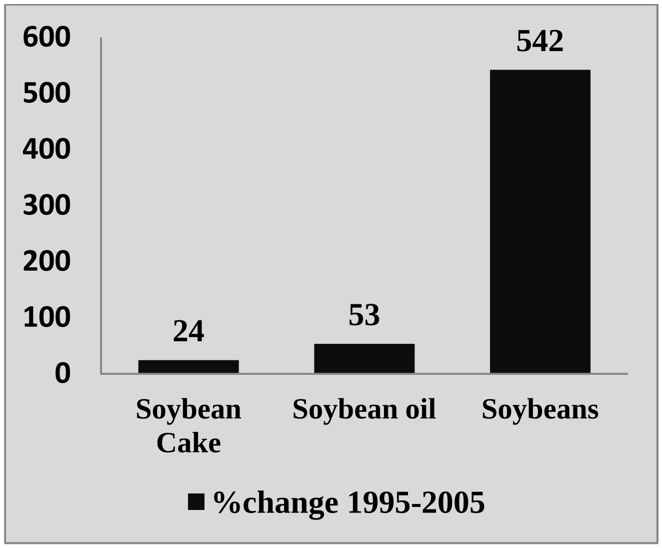

Figure 2.1
Growth in Soybean Exports, 1995-2005(FAO 2011)

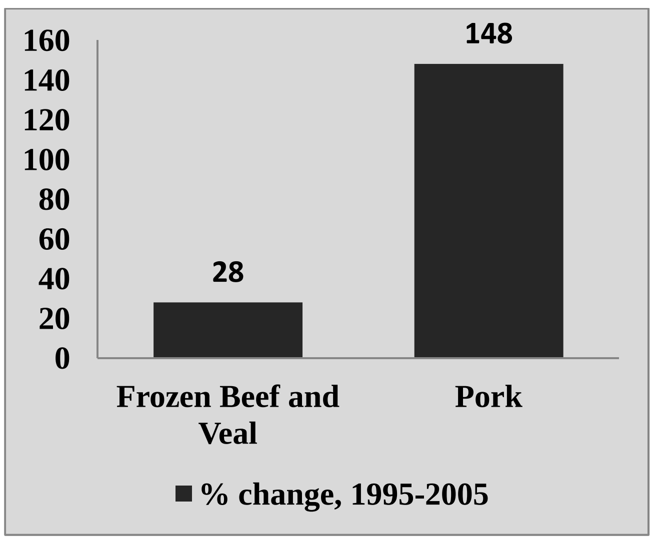

Figure 2.2
Growth in Beef and Pork Exports, 1995-2005 (FAO 2011)

Whereas the devaluation of the real triggered the soybean boom, the more recent appreciation of the currency (against the US dollar) acted to temper growth in agricultural and pastoral areas in Brazil. This suggesting that the pace of growth in export commodities seen at the turn of the millennium is unlikely to be repeated. Nevertheless, the soybean boom and the devaluation of the real led to a rapid increase in Brazil's agricultural exports between 1995 and 2005 (Figures 2.1 and 2.2). During this period Brazil consolidated its place as the world's second largest producer and exporter of soybeans, and shortly thereafter, it would overtake Australia to assume its place as the largest exporter of beef (Food and Agriculture Organization 2011b). Traditionally, Brazilian soybean and beef exports have been destined for Western Europe. Since 2000, however, another trend has emerged, namely the rise of China as a principal export destination for Brazilian resources.

2.6 The Hungry Rise of China and New Export Markets

Whereas Europe had traditionally served as the principal destination for Brazilian soybeans, over the past decade, China, with its burgeoning middle classes, emerged as the principal destination for the Brazil's soybean exports. In 1997, approximately eighty percent of Brazilian soybean exports were destined for Europe, with exports to China accounting for as little as one percent of total soybean shipments (Food and Agriculture Organization 2011b). With the boom in Brazilian agricultural production in place, however, soybeans increasingly were loaded for transport to Asia; by 2001, twenty percent of Brazilian soybean exports were heading to China. Only five years later exports to China surpassed those to Europe, reaching more than ten million tons. The trajectory has since continued, and the gap between China and Europe, now relegated to its position as the second largest importer of Brazilian soybeans, has continued to grow (Food and Agriculture Organization 2011b).

Economists project Chinese demand for meat products, and thus for the soy that is used to fatten the birds, pigs, and cattle, to rise in the coming decades (Caballero, O'Connor and Amado 2011). Indications suggest that China will continue to look to Brazil as a location from which to source natural resource inputs, in essence outsourcing the extensive land inputs needed to support its increasingly urbanized and meat consuming population. Chinese investments have become increasingly prolific in the Amazon, and Chinese interests have sought to invest in the development of the region's infrastructure (e.g., the Tapajos waterways, the Cuiaba-Santarem railroad, and various hydroelectric projects) and seek a greater role in Brazil's political economy(Whalley and Medianu 2010).

It remains to be seen to what extent and to what effect the emerging geopolitical and economic shift by Brazil towards its new consumer base in Asia will have on the Amazonian region. However, it stands that with the primary demand for Brazilian agricultural goods shifting towards China and away from Europe, the importance of the environmental concerns of European consumers may begin to wane.

2.7 Food, Forest, and the Future: Looking Ahead.

Environmental interests the world over took notice as levels of deforestation surged to nearly 30,000 square kilometers, per year during the early parts of past decade. The activities of several non-government organizations (NGOs) assumed a particularly influential role in bringing international attention to the factors driving deforestation in the region, and succeeded in pressuring both public entities and private interests into recognizing the externalized costs associated with rural economic development here (Cargill 2006, Greenpeace 2005b, Greenpeace 2005a). Most notably, Greenpeace succeeded in placing pressure on those who were investing themselves, politically or economically, in an Amazon dominated by an agricultural and pastoral future. Environmentalists scrutinized Cargill's deepwater port at Santarem and even occupied a portion of the facilities for a brief period before temporarily shutting it down on account of a bureaucratic oversight. They also succeeded in placing pressure on Blairo Maggi, Mato Grosso's soybean kingpin and state governor, who was (in)famously awarded Greenpeace's "Golden Chainsaw" as the individual deemed as having "most contributed to Amazon destruction" (Greenpeace 2005b).

Given that ongoing attacks on farmers and the agricultural industry in the region by environmental groups, particularly from Europe, could prove damaging to its long term economic future, both the agricultural sector and the Brazilian government worked with environmental groups to take steps to legitimize production in this region. Several noteworthy initiatives emerged, many of these after 2005 and 2006, when deforestation rates in the Amazon peaked at over 25,000 square kilometers. First, to address the direct impacts of the soybean industry, in 2006 the sector placed a moratorium on the purchase of soybeans produced in areas cleared after 2006 (in the humid moist tropical areas of the basin). Second, NGOs took steps to begin work with agricultural companies to ensure "sustainable" production practices, and to create more environmentally sensitive agricultural practices. Elsewhere in the basin, the nature conservancy and other NGOs began to assume a growing role as mediators with the state bureaucracy, particularly in regard to the environmental management of protected regions and in the formulation of the land titles. Third, the Brazilian government responded with new property regulations for large land holders (larger than 250 square kilometers), including the Cadastro Ambiental Rural (CAR), a georeferenced document formalizing property boundaries and environmental regulations, and the Licencimento Ambiental Rural (LAR), an approved environmental plan for each property were to be required as a prerequisite to public financing or land purchases. Fourth, the government set aside a battery of new protected regions. In 2005, under the Amazon Region Protected Areas Program (ARPA), the federal government established more than 500,000 square kilometers of the protected areas, creating a network of restricted use areas, national forests, and biological reserves (Funbio 2011, Soares-Filho et al. 2008). Many of these areas are located at the margins of the frontier, positioned strategically to minimize deforestation in sensitive areas. That is not to say that deforestation has been exhausted in these areas, some of which remain inhabited, but that rates of forest loss within many of the newly established conservation units have dropped off precipitously (INPE 2011).

At the same time that these new regulations have been put into place, efforts have also been advanced to improve access to the region and spur or sustain its considerable economic growth. Logistical access to the Amazon, in particular, has emerged as a priority to the Brazilian government, with new waterways, railways, and highway pavings taking precedence across the region.

Given that the majority of Brazil's soybean harvests travel long distance by roads, as opposed to waterways or rails (as in the US) the poor state of the nation's road networks has remained an obstacle to the region's economic development; and as of 2005, only approximately twenty percent of highways in Brazil were paved (OECD 2005). Plans are now underway to open new export corridors through or from the Amazon. Given the clear linkage between road building in the region and Amazon deforestation (Pfaff 1999), however, further infrastructure development is increasingly contentious (Fearnside 2006, Fearnside 2007, Fearnside and Lima de Alencastro Graça 2006). Nowhere is this more evident than in the Santarém-Cuiaba (federal highway BR-163) corridor, the unfinished highway corridor that pierces the Amazon forest in a north-south direction. That the highway, if improved, could provide a significant shortcut to port for soybeans destined for export from Mato Grosso, rendered the potential development one of much interest to the soybean (and cattle) sector. And despite intense objections by environmental groups and indigenous representatives, the completion of BR-163, entailing the paving of more than 800 kilometers , has proceeded rapidly.

The agricultural sector is poised for the changes that will come with the asphalt. Cargill's export facilities at Santarém, which now are responsible for loading more than one million metric tons of soybeans (most of which arrives via barge from Porto Velho) per year onto inter-oceanic vessels, is now in the process of expanding its capacity and constructing new storage facilities. The company expects to receive 10,000 additional trucks of soybeans per year, which, at about 3500mt/truck, amounts to 350,000mt/year (Cargill 2010).

The growth in regulation and infrastructure in the Amazon poses a curious duality of economic growth and environmental conservation. This duality in policy aims, however, will likely continue into the foreseeable future, as policy makers and private interests increasingly recognize the importance of maintaining an environmentally tolerable image in the face of pressures to expand economic development. This recognition suggests a considerable shift from the early plans implemented under the military regimes of the 1960s. Slowly, the Brazilian government has shifted in its views of the Amazon, transitioning from a security frontier and later a social frontier, to a frontier led by a mixture of economic investment with environmentally conscious bearings.

The present day product is an environmental reserve offering benefits to the world over, a breadbasket to the world's growing middle classes, and a fountain of capital and foreign exchange. The Brazilian Amazon has transitioned from a frontier of dependency to a region capable of sustaining its own further colonization and capitalization, with high rates of sustained economic growth pulling in additional capital and transforming the region. The transition has taken place partly through the reconfiguration of the military policies of times past, which privileged national security, to a market oriented policy to increase agricultural efficiency through liberalized markets. The following chapter includes a closer examination of the growth of the beef and soybean sectors, as well as their respective roles in driving forest loss in the region.

2.8 Contexts and Conclusion

This chapter was intended to set the land use processes that form the basis of this dissertation within their broader historical, political, and economic context. Several elements in particular were emphasized here as essential to understanding the present day agro-pastoral expansion in the Amazon. These included, first and foremost, the transition from the social frontier driven by economic marginalization in the early periods of Amazon development to a capital frontier driven by market signals and macroeconomic shifts imposed over the decade since the return to democracy. The devaluation of the real at the turn of the millennium and the rise of middle class China as a consumer of Brazilian soybeans and beef was the final ingredient to growth in the soybean sector. Amidst heightened levels of deforestation, policy makers in Brazil and abroad leveraged against unchecked growth in the region, and instituted new policies to attempt to balance economic expansion with environmental protection.

CHAPTER III:

THE DRIVERS OF DEFORESTATION IN THE AMAZON

Researchers have widely examined the driver of deforestation and environmental change. This research has generally indicated that decisions to clear land reflect a synergy of biophysical, social and institutional variables (Geist and Lambin 2001, Geist and Lambin 2002, Meyers 1980, Turner, Meyer and Skole 1994, Keys and McConnell 2005). At the proximate level, this research has implicated agricultural change, logging or wood extraction, and road building or infrastructure improvement as prominent drivers of forest loss. Of the underlying factors, researchers have identified broader economic changes, including the opening of new markets; institutional policies such as land distribution, employment opportunities, and access to employment; technological change, particularly as it relates to agriculture; socio-cultural factors such as environmental values and perceptions of resource availability; and demographic factors, including population growth, urbanization, fertility, and migration (Armenteras et al. 2006, Barbier, Burgess and Grainger 2010, Caldas et al. 2007, Carr 2004, Carr 2009, Chomitz and Thomas 2003, Chowdhury and Turner 2006, Faminow 1997, Fearnside 2008, Hecht 1985, Irwin and Geoghegan 2001, Lubowski et al. 2008, Mann et al. 2010, Mattos and Uhl 1994, Nepstad, Stickler and Almeida 2006, Richards 2011, Richards 2012, Rudel et al. 2009, Salisbury and Schmink 2007, Homma et al. 1993, Walker 2003, Walker, Moran and Anselin 2000).

Not only are the factors that act and interact to drive forest loss myriad, but they act from multiple temporal and spatial scales, and may not be readily evident after an investigation of local or current patterns of forest loss. Whereas past research on land cover change has often focused on local developments, such as changes in local consumption patterns or behaviors, or the evolution of local institutions, new work has increasingly looked at potentially distant drivers behind local processes. Indeed, research has connected changing consumption habits in distant cities and even continents to land use changes in ecologically valuable regions such as the Brazilian Amazon or Indonesia (Rudel et al. 2009, DeFries et al. 2010, Walker et al. 2009b, Walker et al. 2009a).

Within the Amazon, a large region remarkably varied in its biophysical composition and inhabitants, researchers have linked land use changes to a variety of forces, many of which have also evolved over time. Earlier work on deforestation implicated structural issues related to the distribution of land and land tenure and the prioritization of corporate ranching projects (Branford and Glock 1985, Hecht and Cockburn 1989, Foweraker 1981). More recently it has evolved to incorporate policy initiatives tied to globalization and broader corporate interests. With the institution of PIN and an expansion of smallholder colonization programs, as well as spontaneous migration and the occupation of land in the region, a greater recognition of the importance of smallholder patterns of land use rose to the forefront of studies of Amazon deforestation. Much of the work on smallholder land use patterns has incorporated the theoretical foundations of Chayanov's peasant economics and called attention to the role of household production cycles as a driver of forest loss (Walker et al. 2002, Caldas et al. 2007, Moran, Brondizio and VanWey 2005). If changing temporal demands of established households took on a prominent role in the region's forest loss, then the spatial diffusion and movement of rural migrants in the region also occupied an increasingly import role in changing land covers here (Perz 2002, Jepson et al. 2010b, Carr 2009, de Sherbinin et al. 2008, Fearnside 2008).

Today several of these factors continue to be cited as proximate drivers of the region's forest loss in the Brazilian Amazon, including hydroelectric projects, mining, timber extraction, agriculture (both as perpetuated by large and smallholder producers) and cattle production. Of these, the latter is considered to be responsible for the overwhelming majority of deforestation in the region (Faminow 1997). Given the low levels of capital and labor inputs required to create and sustain production in the Amazon, cattle ranching remains the principal economic activity of both large ranches and, increasingly, smallholder operations (Walker et al. 2000, Salisbury and Schmink 2007). However, most recently, with rapid growth in soybean production, attention has shifted to the role of large scale agricultural commodity production as a driver of deforestation (Galford et al. 2008, Morton et al. 2006, Brown et al. 2005). Broadly, much of this work has pointed back to the drivers that underlie the expansion of soybean and beef production, both of which are linked to macroeconomic patterns or international markets. Here, research has indicated that as distant consumers are connected to products cultivated or slaughtered in the Amazon biome, international prices for globally traded commodities will take on a greater role in shaping landscapes in even these long marginalized economic regions (Walker et al. 2009a, Nepstad et al. 2006). In the present chapter I provide an overview of the beef and soybean sectors, the two principal drivers of deforestation of interest to this study. I begin by differentiating the land use impacts of beef and soybeans from those of the extractive industries that were fundamental to the region's economy of times past. I then consider, in turn, the evolution of the cattle and soybean sectors and the factors and forces that engendered their recent growth.

3.1 Employing Land, not Forest

The growth of agriculture and ranching differs in many respects from earlier economic booms in the Amazon. To understand why where earlier economic booms have led to fantastic busts, the present day cattle and soybean based economy of the region is likely to remain, it is essential to consider two of these differences.

First and foremost, the present day economy of the Brazilian Amazon (dominated by ranching and agriculture) eschews the forest itself as a factor in production. Rather than seeking the fruits of the forest, it seeks instead to capture the power of the soils upon which the forest once stood. In this sense, the forest was an essential input rather than an obstruction to production to both the rubber boom of the turn of the 20th century and the Brazil nut boom that followed in its wake. It was not the land in itself that created value, but rather the vegetative ornaments that graced it.

Second, and also in contrast to earlier economic activities in the region (e.g. the collection of rubber and Brazil nuts) the spatial concentration of agricultural and cattle profits enables ca multiplier effect, or the emergence of secondary and support industries. In this respect, scholars have argued, the spatial distribution of species central to the earlier extractive activities played a role in mitigating both land use change and the broader economic development of the Amazon (Barnham and Coomes 1996). Peculiarities in species concentration, and the difficulty of managing plantations or orchards in the Amazon proved exceedingly difficult for those seeking to more efficiently orchestrate the harvest and gathering of the fruits of the forest. In the ultra-efficient Amazonian ecosystems, species concentration, it was realized, could prove undoing as low species diversity resulted in an environment fertile for predatory organism to proliferate, and to potentially gain the required strength needed to decimate their spatially immobile hosts. Indeed, attempts to grow black pepper, rubber, and cupuaçu (an Amazon fruit widely consumed across Brazil) in plantation form were, at various places and times across the Amazon, ultimately foiled by plant pathogens feasting upon the relative ease in accessibility of their concentrated, monocultivated hosts (de Souza et al. 2011).

The dispersal of trees responsible for the fruits and saps once demanded by outside economies meant that, historically, workers and capital invested in the harvesting of forest products were as broadly disseminated as the trees themselves (Barham and Coomes 1996, Barnham and Coomes 1994). Consequently, many of the foot soldiers of the region's extractive booms found themselves marooned alone or in small work teams in distant tributaries of the Amazon watershed, in essence reducing the potential returns to scale and multiplier effects that could have led to a more developed rural economy. More broadly, the low levels of invested capital in relation to each unit of land resulted in a lingering impediment to the region's development. While several cities emerged (notably including Porto Velho, Manaus, Santarém, and Belém) along the river itself, largely as catchments for latex shipped downstream for export or as stopping points for an opulent array of merchandise moving upstream, from opera to European laundered couture, the wide dispersion of capital invested across the breath of the Amazon's interior was insufficient to sustain broader economic growth and ancillary productive sectors (Barham and Coomes 1996). In this sense, the very magnitude of the Amazon and the diffusion of the species that it harbored served as a mechanism in and of itself capable of warding off those who sought to capture anything more than the goods of the forest.

Many of those who initially did see the potential in the Amazon Basin's expansive areas of unexploited land, favorable tropical climate, and ample rainfall, famously failed in their attempt to capture it, often succumbing to the extreme isolation of the region and the difficulties of cultivating plantation style agriculture in the midst of this unique biome. Most notably, Daniel Ludwig's Jarí project in northern Pará, and Ford's agricultural utopia at Fordland (and later, Belters) endured not as capitalist success stories but as the black legacies of successful entrepreneurs whose rainforest gambles proved untenable (Grandin 2009). The intentions of these foreign capitalists, however, may simply have preceded their time; capturing the power of the Amazon Basin's soils, not its vegetation, has become the fundamental pursuit of those who seek land here today

More recent endeavors to capture the Amazon's resources for economic gain have proved highly successful, and over the past forty years Brazil has ceded the environmental wealth of the Amazon Basin in favor of sustained growth in economic wealth, development and colonization. In contrast to earlier economic booms that were exploitive of the region's natural forest products, the more recent development of the Brazilian Amazon, linked to the capture of land for the production of commodities destined for global markets, is not dependent on the forest, but rather on the soils upon which the forest once stood and on the rumbling stomachs of distant consumers (Falesi 1976, Fearnside 1990). Thus, in contrast to initial calls to the Amazon Basin to gather Brazil nuts or to tap the latex of *heavea* trees, activities which required the manipulation of forest rather than its clearing; much of the new economic development of the Brazilian Amazon has called to various degrees for its extirpation. As indicated in the preceding chapters, first the cattle sector, and later, also the soybean sector, reshaped the economic landscape of the region. I consider the growth of each of these sectors in the ensuing section.

3.2 From Bezerro to Boi, Fattening the Brazilian Cattle Sector

Historians have traced cattle production in the Amazon Basin back to Marájo Island and the early 1700s, where and when the animals were first introduced to take advantage of the region's natural grasslands (Teixeira 1953). It was only in the 1960s, with the construction of the Belém-Brasilia highway and the institutionalizing of fiscal incentives as part and parcel to *Operation Amazonia*, however, that the cattle sector entrenched itself in the upland portions of the basin (Browder 1988, Hecht 1985, Mahar 1979).

At the outset of Brazil's Amazonian development, settlers, and the policy makers that sought to bring people to the region, identified ranching, its minimal costs in labor and capital, and the ease of planting pastures, as one of the few viable production sectors in the region. Not only was cattle production seen as being economically viable, it was also originally believed that the creation of pastures and the burning of forest actually led to the neutralizing (and in this case, hence an improvement) of the region's acidic soils (Falesi 1976). Such claims helped to direct Brazil's Amazon development policies toward the furthering of the cattle sector, and thus away from a longstanding emphasis on extractive goods or agriculture (Fearnside 1990). With time, however, researchers raised questions over both the supposed environmental benefits of cattle and the long term economic viability of the sector (Fearnside 1990).

In the 1980s, further studies on the relationship between ranching and long term soil capacities also cast doubt on the capacity of the region to sustain production (Fearnside 1990). This research pointed out that many ranching operations faced rapidly declining pasture yields in the years following clearing. As yields declined, pastures were left fallow, and ranchers needed to clear new lands to maintain production levels, generally at a pace that exceeded the forest's natural regenerative processes (Homma et al. 1993). Given that new clearings for pasture carried a clear environmental cost, questions emerged over the true costs and benefits of grazing cattle in the region.

Notwithstanding the environmental costs of opening new pastures, political ecologists also raised questions over whether the generous array of subsidies accommodating ranching in the region had the effect of rendering a losing economic strategy a positive one (Hecht 1985). However, while generous subsidies to large ranching projects in the Brazilian Amazon did draw extensive cattle ventures into the region, it nevertheless remains that many ranches were established without the benefits of government largesse (Walker et al. 2009b). And given the nature of frontier cattle ranching as an extremely low human and capital input and land extensive operation, and the plentiful rainfall and seemingly endless reserves of available land in the region, cattle ranching in the Amazon uplands was quite profitable, with returns exceeding those in the traditional grazing areas of the basin (Arima and Uhl 1997, Mattos and Uhl 1994). The facility of planting pastures in remote areas, combined with the skeleton network of publically financed roads and highways imposed in the 1960s, in fact, made cattle ranching one of the few profitable economic ventures in the region and an engine for economic growth (Arima and Uhl 1997).

Amazon scholars have traced the more recent growth of the Amazon cattle herd to several important developments beyond the broader economic initiatives I described in the previous chapter. Perhaps most important of these was (a) the development of Nellore cattle, (b) the eradication of foot and mouth disease in the late 1990s, and (c) the broader improvement of roads and access across the Brazilian Amazon played important roles in engendering the growth of production in this region (Walker et al. 2009b). Each of these developments warrants additional description.

The Nellore descends primarily from Zebu cattle, a breed that is regarded as hardier and more adapted to the moister and warmer climates of Brazil's interior than their European counterparts (Sanders 1980, Kelley 1959). When crossed with European cattle (which were already bred for meat production), the result was a hardy breed adequate for beef production in tropical regions. The Nellore takes on many of the features of the Zebu, including its prominent white hump and the long legs that allow the race to thrive in wetter climates and to some extent avoid predatory insects. Ranchers in the Amazon suggested during interviews that the animals require only the most minimal medical attention and do not need the same inoculations against ticks required by other breeds. Indeed, studies appear to confirm that the hardier purebred Nellore show a strong resistance against tick borne illnesses, though the results are less conclusive for cross bred animals (Gomes et al. 1989). Ranchers also suggested during conversations in the field that the breed was capable of calving with little or no attention from ranch hands and that it was generally better suited to the tropical environments of the Amazon. The opinion, evidently, is widely shared by ranchers in Brazil. Today, Nellore cattle are ubiquitous across the Amazon landscape, and the breed dominates the Brazilian cattle sector. More importantly, the hardier nature of Nellore cattle allows ranchers to graze the animals on extensive pastures in frontier regions, and with only the most minimal supervision and attention.

If the development of Nellore cattle represented a technological improvement to the Amazon cattle sector, the eradication of foot and mouth disease provided an improvement in market access. Through the 1990s, foot and mouth disease limited Brazilian beef exports (PNEFA 2008). However, through the gradual eradication of the disease from the Brazilian herd in the latter years of the decade, the Brazilian government was able to its domestic beef industry to international markets. By 1998, successes in the program would allow the first foot and mouth free zone in Brazil to be established in the southern States of Rio Grande do Sul and Santa Catarina. By 2002, the government expanded this to include much of Brazil's Center-West and southern and southeastern states, as well as portions of the Amazon States of Pará and Rondônia. The control of foot and mouth meant that not only could cattle produced in areas of the Brazilian

Amazon be prepared for export, but it could also travel southward, as travel between zones declared free or contaminated with foot and mouth had been prohibited (PNEFA 2008). The removal of these restrictions opened much of Brazil's Amazon region to national and international markets.

The combination of technological advances in the fight against foot and mouth disease rendered the classical ranching economy of the Iberian Peninsula capable of extension into the Amazon. Combined with reductions in travel costs, production was suddenly viable in even many of the most distant frontiers in the region. Cattle ranchers in the Brazilian Amazon could supply beef to relatively local abattoirs, which could then ship their produce southward to Brazil's substantial national markets clustered along the coast (Walker et al. 2009a). Cumulatively, the developments acted to turn the Amazon range from one focused on local production and land speculation into one serving global markets.

With these developments cattle populations in the Amazon expanded rapidly (figure 3.1). In the mid-1970s, less than ten million cattle were grazing across the entirety of the Legal Amazon. By 1990 that figure had nearly tripled, growing from eight to twenty-five million animals. By 2000 and then 2010, cattle populations had reached forty four and then seventy-seven million. The seventy-seven million cattle currently grazing in the Amazon now account for more than thirty-six percent of the Brazilian herd, double the thirty-seven million head stocked in the region in 1995, when cattle here comprised only twenty-two percent of the national herd (IBGE 2011b).

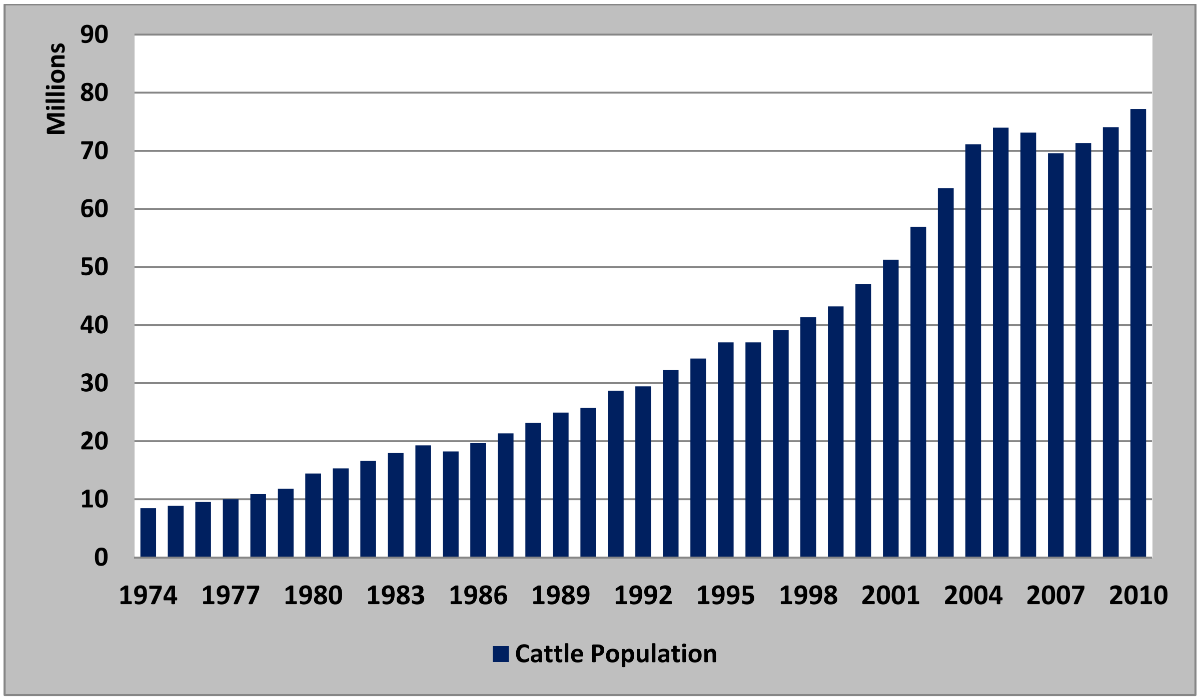

Figure 3.1.
Evolution of the Amazon Cattle Herd, 1974-2010

For interpretation to the references to color in this and all other figures, the reader is referred to the electronic version of this dissertation

Although the extent of beef exports produced in Brazilian Amazonia remains unclear, exports directly from the Amazon are likely minimal in relation to the totality of those emanating from Brazil, which overtook Australia as the largest exporter of frozen beef in 2005 (Food and Agriculture Organization 2011b). However, even if beef from the Brazilian Amazon is not being shipped abroad, it does appear to be feeding the substantial national market and the more populated districts in the nation's south. In any case, much of the growth in Brazilian supply has occurred through an increase the nation's Amazon herd; and given that much of the nation's beef is consumed internationally it follows that international demands for beef have played an important role in drawing new production into the Amazon. The so-called Hamburger connection, developed in the 1980s to link American fast food to deforestation tied to expanding cattle production in Central America, has only come to bear in Brazil over the past decades (Kaimowitz et al. 2004).

The connections between forest loss in the Amazon and the expansion of beef production have long been established, and clearings for new pastures account for the majority of forest loss in the Amazon (Andersen et al. 2002, Faminow 1998, Faminow 1997). The timber industry continues to play an important role in facilitating the movement of cattle production into the interior through the creation of secondary and tertiary access roads, as well as the thinning of dense forest strands; however, though logging certainly damages the forest, logging impacts are minimal in comparison to ranching. In contrast, for ranchers, the forest is an absolute impediment to production; they can only establish pastures through its destruction. Though the deforestation process generally begins with the extraction of the larger and more valuable tree species, often by the timber industry, it thus ends with the clearing of the remaining forest for pasture.

The means by which the forest is cleared depends on the rancher's (or farmer's) access to machinery and capital. Well financed farmers and ranchers, particularly in the less dense transitional areas at the periphery of the Amazon biome may open lands by stretching a large chain between two tractors (Jepson et al. 2010a). The tractors move through the forest in tandem, with the chain removing the forest between them. For smallholders, a farmhand and a chainsaw suffice, with vegetation larger than the size of an arm removed by the saw; and a single worker capable of clearing as much as two ha per day. Once the landowner succeeds in decapitating the vegetation, subsequent burnings of the drying, desiccated biomass further opens the area. For larger ranchers grasses can be seeded by aircraft, typically before the first rains.

The relatively minimal effort required to open forest in this way, combined with the fact that cattle are inherently mobile creatures (ranch hands can walk their product to market if necessary) and require only minimal labor inputs to produce, means that ranchers can establish pastures in even some of the most distant and economically marginal locations. Consequently, beef production remains the principal driver of deforestation in the Amazon, though another factor, namely the soybean sector, has gained much attention in recent years.

3.3 Soybeans in the Amazon

If cattle production in the Amazon has long drawn the gaze of environmentalists and those concerned with the loss of the region's forest, it is only more recently that this has become true for the broad-acre agricultural sector. The emergence of soybean production in the Amazon has, if only in recent years, added another dimension to the tenuous balance between economic development and environmental destruction.

Soybeans were first introduced to Brazil in the early 20th century, probably by Japanese immigrants to the São Paulo region. More widespread production did not begin to occur until some decades later, when soybeans were employed as forage and green manure crops in the southern states of Rio Grande do Sul and Santa Catarina. Soybeans, which originated with the longer days of the temperate latitudes, were naturally more suited to Brazil's southern states than regions farther north. Even in the south, however, the soybean sector remained minimal in comparison to other staple crops such as wheat and rice, and produce was initially destined for farm level animal fattening or for reseeding as a green manure crop (Warnken 2002).

In the 1970s the sector experienced its first period of tremendous growth, as climatic events associated with El Niño combined to diminish fish harvests off the coast of Peru and led to drought in central Africa. The climatic effects on production of alternative protein sources occurred simultaneous to a series of large grain buys by the Soviet Union, resulting in a dual shock in both demand and supply and triggered a global shortage of high protein oils and meals. The result was a rush to one of the few available alternatives, soybean meal (Warnken 2002). The sudden demand for soybean meal was of such impact that the United States briefly chose to ban exports of the good, a move that resulted in a short commodity panic in Western Europe and Asia and, ultimately, a frantic desire for importers to seek out new, non-U.S. based suppliers. Southern Brazil, where the crop was already present, was seen as a possible solution, and soybean production here expanded rapidly, leading to the displacement of smallholder farms and farmers that had traditionally produced labor intensive goods such as cotton or coffee (Margolis 1973, Foweraker 1981).

Of those displaced by the hollowing frontier in southern Brazil, some crossed the border to settle in agricultural colonies in eastern Paraguay (Richards 2011, Nickson 1981). Many more moved northward toward Mato Grosso (Jepson 2006a). Many of those who migrated were farmers by trade, and their movement represented the relocation of not only people, but skills, and in some cases, capital, from Brazil's agricultural districts in the south to the southern Amazon Basin. Yet if those arriving to the Brazilian Amazon frontiers during this period had arrived with the intention of planting rice or coffee, they were to be deeply disappointed, as the conditions of the cerrado and the Amazon soils were less conducive to their production, and difficult access impeded the transfer of their crop to potential markets in the south. Potential soybean producers faced additional obstacles, as the low latitudes and short daylight hours of central Brazil inhibited the plant's growth. In the 1990s, however, an improving infrastructure and advancements in planting practices and seed technology, including the adaptation of the soybean to the low latitudes of central Brazil, boosted yields and rendered soybean production more viable, even in the southern Amazon.

The advancement of soybean production in Mato Grosso, where the crop first emerged as a successful agricultural strategy in the 1990s, was aided by not only technical advancements, but also several inherent institutional factors favoring the production of commodity crops. The presence of settlement cooperatives and colonization companies, for example, often meant that farmers had both an intermediate agency with which to act to secure federal assistance during the early periods of colonization and a local mechanism through which to disseminate ideas and planting techniques. Owing in part to the colonization scheme present across much of the state, many of the farmers that arrived in private colonization initiatives in Mato Grosso were more likely to have access to the both the mechanized inputs required for crop production and the know-how regarding how to use them (Jepson 2006a, Jepson et al. 2010a).

At this point it is important to note that while soybeans are emphasized as the embodiment of the commercial agricultural sector in the Amazon, the crop is rarely grown in perpetual mono-cultivation. Rather, soybeans are often rotated with corn or may be double-cropped with corn, millet (which may or may not be harvested, but is often planted regardless as a cover crop), sorghum, or cotton. It is soybeans, however, which drives this cropping system, and which is emblematic of the region's agricultural expansion. Soybeans are generally planted with the early rains of the austral spring, usually in late October or early November, with harvesting done in February or March; if a second crop is to be planted, it must be done immediately after the first harvest. Planting a second cash crop, usually corn or cotton, may be risky, and whether or not a second crop is planted depends in part on the timing of the initial harvests, and on the quantity and timing of rains during these periods. If the land manager decides not to plant a second cash crop then a cover crop is generally seeded, usually millet, which often remains unharvested but which serves as an important cover crop.

With the shift in national economic policies outlined in the previous chapter, soybean production expanded rapidly across areas in Brazil in the late 1990s and early 2000s, but nowhere more so than in Mato Grosso State. Today, Mato Grosso alone now produces more than one-third of Brazil's soybean exports, or about one-eighth of the global supply (IBGE 2011a). The growth in soybean production, particularly in Mato Grosso, has led to concerns that agriculture is emerging as a significant, if secondary, driver of deforestation in the Amazon. Thus although cattle production remains at the forefront of deforestation, from the early 2000s it was also increasingly recognized that the large scale expansion of agricultural production in the Amazon had assumed an important role in the process. From 2000-2005, as soybean production was rapidly expanding, deforestation spiked upward, drawing attention to the potential linkages between the soybean sector and Amazonian deforestation (INPE 2011). The installment of Cargill's deep water port on the Amazon River at Santarém and discussions regarding whether or not to pave what was then becoming known as the soybean highway, BR-163, drew additional attention to the potential environmental implications of producing soybeans in the region.

At the same time as public consciousness was beginning to recognize possible linkages between deforestation and food production, studies on land change in the Amazon began to offer tangible evidence of the soybean sector's impacts. Several remote sensing studies, which were able to discern land use between agriculture, pasture and forest cover through variations in vegetation phenology, suggested that as much as twenty-three percent of areas deforested in Mato Grosso were being converted directly to agriculture (Morton et al. 2006). These findings were somewhat in juxtaposition with thinking that soybeans are more likely to occupy existing pastures than to clear new forest lands, given the expected cost of preparing forest areas for agricultural production (Margulis 2004, Richards 2012). However, given the importance of increasing returns to scale to soybean producers and local producers' institutions to keep costs low, and thus the importance of proximity to existing soybean centers (Garrett, Lambin and Naylor (Forthcoming)), forested areas near to existing soybean sectors may be attractive locations for direct conversion for agriculture.

Nevertheless, it is important to recognize that when or where agricultural production occurs directly in the wake of forest clearings, it has generally been done so only in areas peripheral to existing zones of soybean production. Just as the nature of the cattle industry has often positioned production in the most marginal areas, soybean production has generally clustered in zones of production, allowing farmers to take advantage of not only easier access to port facilities or silage, but also to the increasing returns to scale that are vital to the sector. It is essential to recognize that, in contrast to cattle ranchers, farmers remain heavily dependent on the presence of their support industries, from financers and truckers, to seed venders, mechanics and purchasing agents, and thus are limited in how far they are likely to move into the frontier. For whereas ranchers may only require limited supplies of fencing, labor, vaccines and animals in order to commence their operations, soybean planters require annual access to large quantities of seed, fertilizer, diesel fuel, and harvesting and planting machines. This is in addition to access to pre-harvest financing, silage for crops post-harvest and extensive trucking capacities with which to move the goods to port. Consequently, the growth in soybean production in the Amazon, and particularly in Mato Grosso, has largely stemmed outward from several production poles: from Rondonopolis, in the southeast; Commodoro and Vilhena (Rondônia) in the west, and Sorriso and Lucas do Rio Verde in the north. Outside of Mato Grosso, islands of soybean production have also emerged in Paragominas and elsewhere in northeast Pará and in Santarém. And still more recently, new zones of production have expanded in the once remote region known as MaToPiBa (located at the confluence of the States of **Ma**ranhão, **To**cantins, **Pi**aui, and **Ba**hia), where land remains relatively affordable and topography and rainfall levels are favorable to production.

Although soybeans have been identified as a direct driver of forest loss (Macedo et al. 2012, Morton et al. 2006), the crop's expansion of production generally occurs through the occupation of existing pastures (Margulis 2004). This occurs for several reasons. First, farmers intending to convert forest lands directly to agriculture face the obstacle of meticulously preparing land for production. Because soybeans grow relatively close to the ground, harvesting machines must be set at a low clearance height. Consequently, before production can take place, in addition to correcting the natural acidity of many of the soils here, farmers must ensure the complete removal of any stumpage or other vegetative detritus before planting. Presently, farmers that open new land typically will cultivate rice for 1-2 seasons prior to planting soybeans to more fully prepare land for production (USDA 2007). By acquiring pasture, however, this interim period can at times be avoided. Thus farmers looking to expand their production may be more likely to search out existing pastures than standing forests.

Politically, deforesting land also has become an increasingly difficult activity, as sector-specific regulations limit forest clearings and the government enforces existing limitations for the first time. The consequences of illegal deforestation are in some places being felt, often through restrictions on farmers' abilities to obtain financing; this has left those who have over cleared the land subjected to bankruptcy in unfavorable years, as farmers are unable to make up losses by leveraging their land for additional capital. More broadly, soybean production requires a significant investment in land, and before farmers choose to make such an investment any ambiguities related to property ownership or land use they will have a strong incentive to make sure that such issues are resolved. For many farmers, the potential negatives associated with clearing new land have directed those looking to expand to increasingly look towards lands that have already been opened. For ranchers, or for loggers who act to degrade the forest but not clear it, many of these disincentives are reduced, if not inapplicable.

Another relatively new, institutional impediment to expanding production into standing forests is the well known soybean moratorium, the industry led black list meant to inhibit the expansion of new soybean production into recently cleared areas (Brannstrom et al. 2012). The soy moratorium was officially imposed in 2006 when the member companies of ABIOVE (Brazilian Vegetable Oil Industry Association) and ANEC (Brazilian Grain Exporters Association) agreed not to trade in soybeans cultivated in areas in the Amazon Biome deforested after July 2006. This so-called soy moratorium, which was written outside of the public sphere, was widely hailed by international NGOs, including Conservation International, Greenpeace, The Nature Conservancy, and the World Wildlife Foundation and other NGOs, many of who were involved in the agreement. Rather than affecting farmers directly, several grain purchasers would mutually agree not to purchase soybeans from any property that had been deforested after the moratorium was imposed.

While the farm level impacts of the moratorium remain unclear, an analysis of areas deforested since the moratorium was put into place suggests that only approximately 63 square kilometers of areas deforested since the moratorium are now planted with soybeans, or about 0.37 percent of areas deforested in the Amazon biome in the States of Mato Grosso, Pará, and Rondônia (Rudorff et al. 2011). Whether or not farmers planting in areas protected under the moratorium are able to sell their soybeans, and to who, also remains unclear. At a smaller scale, it is likely that farmers may be able to sell soybeans for local consumption, or destined for feed at local poultry processors.

If the direct effects on forest cover associated with soybean production are considered to be largely mitigated, another effect, namely one associated with indirect land use change, remains of some concern. What happens to the owners of areas converted from pasture to soybeans, or to beef markets as pastures are occupied for croplands has become of some interest to policy makers. If losses in areas dedicated to pasture were resulting in a loss in beef supply, and hence higher prices for beef, or perhaps the displacement of cattle ranchers to more marginal locations, then soybean production may be tied indirectly to the loss of the Amazon's remaining forests. Such linkages between the expansion of soybeans and cattle indeed have been suggested, both through statistical inference and in theory, with further implications in regional forest loss across the Amazon (Barona et al. 2010, Lapola et al. 2010, Arima et al. 2011, Almeida de Menezes and Piketty 2007). However, the mechanisms by which this occurs nonetheless remain somewhat unclear, given the difficulties in tying land use change in one location to another, potentially distant one. The following chapter is designed to clarify the underlying mechanics of this process and to set the theoretical foundations for the remainder of the dissertation.

Before proceeding, it is essential to acknowledge that the drivers of deforestation are certainly myriad across the Amazon Basin. Over the past decades many have considered the progression of a frontier as one commenced by timber companies, followed by smallholder farmers and later ranchers, and only then by commodity farmers. This process may indeed be occurring in regions of the Amazon, and may continue to be prevalent elsewhere in the basin, and particularly in those regions with a history of spontaneous settlements in Brazil or in the seven other nations that claim ownership of portions of the basin. However, the emergence (and evidence thereof) of commodity farming as both a direct (and indirect) driver of deforestation continues to mount in areas exhibiting high rates of deforestation.

CHAPTER IV

FRAMING INDIRECT LAND USE CHANGE AND THE LOCATION-UTILITY MODEL

The theoretical approach of this dissertation stems from a reconfiguration of location theory, the land use model tied to the conceptual diagrams of the German economist, J.H. von Thünen, and acknowledges the neoclassical models of migration often associated with Sjaastad (1962). The dual framework offers a means by which to close the structural-agency binary in land use studies (Chowdhury and Turner 2006) by conditioning individual agent based decisions with a broader spatial structure, in this case built on distance and transportation costs (Angelsen 2007, Walker et al. 2009a).

In this dissertation I recognize that the Thunian formulation of location rents has been heavily criticized for a perceived discounting of complexity, environmental factors, and human relations (Barnes 2001), and even for supposed relations to the military-industrial complex residual to the mid-century (Barnes 2012). These criticisms have largely encompassed three principal assumptions or omissions: (1) an equilibrium assumption, or where the Thunian formulation is viewed as static, in contradiction to the change that is fundamental to many of the studies of land use *change*; (2) the positivist reduction of location rents to a geographic consignment concentric rings around a single core market; and (3) the detachment of the Thunian land use structure from individual, agent based decisions (Walker and Richards Forthcoming). Yet each of these criticisms is relevant only to a caricature of the rent model, rather than as a guiding conceptual form that situates land use decisions within a spatial landscape of production opportunities. The present text rather adopts an avenue of approach where I conceptualize the

Thunian model as not a positivist declaration of land use, but rather as suggestive of general land use trends that occur over a broader temporal horizon. I recognize the importance of diversity of environmental factors, as well as the complexity imparted as multiple points of consumption and distribution appear and interact across a landscape. And as I will stress throughout this chapter, I also acknowledge the importance of individual, agent level behaviors as the fundamental drivers of land use change and in shaping a broader, regional-scale economic landscape.

Specifically, this dissertation draws from an institutional and political-economic approach associated with von Thünen and landscape change. This approach, used by Cronon in his analyses of the regional landscapes of the Midwest and Chicago (Cronon 1991) and by Peet in his work on international trade and its impact on broader changes in land use in North America (Peet 1969), draws from the conceptual fruits of rent theory while eschewing its positivist reductions. This dissertation is in essential agreement with these institutional economic and political economy approaches.

This approach has already been used to explain the advance of Brazil's Amazonian agricultural frontier as part and parcel of capitalist penetration and as the movement of private organizations. This advance has been shown to have emerged from the centers of commerce and production in the southern part of Brazil, replacing the autarkic economies of Brazilian Amazônia with modern modes of production as it proceeded northward (Mahar 1979, Foweraker 1981, Schmink and Wood 1992, Branford and Glock 1985, Hecht and Cockburn 1989, Margolis 1973, Alston et al. 1999, Jepson 2006b, Brannstrom and Filippi. 2008, Ianni 1979, Martins 1975, Sawyer 1984, Bernardes 2007). As transportation costs declined and market prices for traded commodities increased, new areas were captured for production and the frontier extended outward.

Concepts of location and rent theory largely are implicit in much of this work, though this has changed in recent years, with Thunian land rents assuming a more prominent role in academic discussions of the Amazon's advancing agricultural and pastoral frontiers. With the Amazon becoming increasingly integrated into the broader market economy, land uses here have shifted rapidly, with agriculture and pasture expanding and forests contracting (Bowman et al. 2012, Vera-Diaz et al. 2008, Mann et al. 2010). The Thünian formulation is able to articulate these shifts and the advancing, market based, agricultural and pastoral frontiers in explicitly spatial terms, a component that is essential to the present research, and which allows me to link frontiers through a spatial structures built on land rents and transportation costs.

The frontier, whether as a dynamic point of transition or as an adjective defining a chaotic peculiarity associated with a certain class of places, has been broadly defined and is a fundamental concept in this dissertation. F.J. Turner (1986) who first posited his frontier thesis in the early 20th century, suggested that the frontier is both a process and a moving entity that both was shaped by and shaped those that experienced or lived within it. It was the divide between society and nature; and its settling represented both the transformation of the wilderness and of people. Watts (1992) viewed the frontier as a space of ideology and economy, or as "the first wave of modernity to break on the shores of an uncharted heartland" (p 116). Others have viewed the frontier as the transition between subsistence or autarchic economies and market based, integrated production strategies (Katzman 1977, Cleary 1993). The frontier is a critical concept to this dissertation, and one which I define as where commodity based agriculture or ranching advances on subsistence farming or uncultivated wilderness (Walker 2004, Walker and Solecki 2004, Jepson 2006b). This viewpoint draws implicitly from Polanyi and the capturing of space through the creation of market space, or the commoditization of resources, whether people or nature (Polanyi 1944).

In considering the frontier and frontier dynamics as a process of commoditization and the transition from non-market to market spaces, this research also subscribes to a growing interest in the flow of capital and capital intensive production systems in the Amazon basin (e.g. Brown et al., 2005; Hecht 2005; Jepson et al., 2006a; Jepson et al., 2006b; Bernardes et al., 2007; Brown et al., 2007; Walker et al., 2008). The frontier in this regard is not merely a space where land is settled and forests are cleared, but rather one where land is being commoditized and capitalized. As I will discuss later in the ensuing chapters, private colonization companies facilitated this commoditization of space by offering a degree of regulation and capitalization where spontaneous and state sponsored projects could or did not (Jepson 2006a). Elsewhere in the Brazilian Amazon, ambiguities in property rights and land tenure could work to maintain a frontier environment, with a lack of access to title inhibiting investment and producer mobility.

One of the principal conceptual underpinnings to this dissertation is that both a capitalized, agricultural frontier and an extensive cattle frontier expand (or contract) together. Where the cattle frontier first captures land for production and clears from it its vegetative ornaments, the agricultural frontier consolidates it as a capitalized frontier, or where land, now safely commoditized, stands ripened for investment and intensive production. One land use follows the other, both as a symptom of market effects and product elasticities, and via the displacement of human and financial capital. The spatial linkages that underlie this process form the fundamental basis from which the concept of indirect land use change ultimately emerges in this dissertation.

The linkages between the advancement of a capitalized, agricultural frontier and the extensive cattle frontier are conceptualized here through two means. First, a linkage emerges through a spatial effect transmitted via land prices, or through land appreciation. As the demand for land increases the value of land also rises, which allows land owners to capitalize on its value. Here, I call upon the neoclassical theories of migration associated with Sjaastad (1962), which I later situate explicitly within a landscape structure built on land rents. In addition to location-specific drivers of land use change, I view the movement of resources, including people and capital, as fundamental to both the formation of the frontier and the realization of potential rents. By focusing on the movement of resources, including people and capital, I call explicitly on theories of migration.

Migration itself has already been closely linked to deforestation in tropical regions, where it acts to reshape both demographics and the landscape they populate (Carr 2009, Pan et al. 2003, Bilsborrow 1987, Perz 2002). Conceptually, research has theorized migration as incentivized by a series of push and pull factors associated with migrants' origins and potential destinations. Several frameworks have emerged to conceptualize ties between migrants and the environment particularly in rural, tropical regions (see Caviglia-Harris et al. 2012 for a full review). These include (1) hypotheses that migration is linked to age of household, with younger, second generation household members seeking to establish their livelihoods by seeking new land (Brondizio et al. 2002); (2) a path dependence framework, where poor families repeatedly seek and fail to establish successful farms due to lack of access to capital; (3) the so-called turnover hypothesis or hollow frontier thesis, where unsustainable farming practices leads to land degradation; and thus forces small farmers to seek new areas for production (Pichon 1997, Rudel, Bates and Machinguiashi 2002); and (4), the frontier expansion framework, where economic conditions propel an exploited class of workers into nature to extract value. This latter framework is akin, in part, to the "Turner read backward" approach posited by Cronon in his analysis of Chicago's role in driving and benefiting from the extension of the American agricultural frontier into the plains region (Cronon 1991).

In this research I incorporate aspects of the so-called frontier expansion conceptualization of migration. However, in contrast to much of the earlier work on migration in tropical regions, and in the Brazilian Amazon in particular, where researchers have focused on the migration of smallholder farmers perpetuating a semi-autarkic or subsistence livelihood, I turn to the migration of labor skilled in the production of traded commodities. In doing so, I suggest that migration is a function of opportunity costs, or that potential migrants seek to maximize the potential returns to their set of skills and capital. This supposes that farmers and ranchers will seek to maximize their utility, subject to constraints to their prescribed skill set and their access to inputs, including land. This first assumption is closely related to the push and pull factors commonly cited in literature on the migration of smallholder farmers in the Amazon; however, here, landowners seek to maximize the returns to their specific skill set (Sjaastad 1962), which in this case is dependent on a spatial structure defined partially through transportation costs and the location rent model of von Thünen, through natural variations in physical characteristics such as topography and precipitation, and differentiable institutions, such as property rights, and cooperative organizations.

This research thus also assumes that farmers and ranchers producing for external markets are relatively and inherently mobile; they not only choose their economic behavior based on utility maximization (subject to their location, but rather), given the individualized set of acquired skills that they possess, they may chose to maximize utility by choosing location. The movement and availability of skills and capital takes on a particularly important place in this research, and land use change is here viewed as contingent upon the migration or development of production knowledge. In this sense, land use change is incentivized by shifts within the broader economic rent structure, but any changes effected ultimately must rest upon the mobile shoulders of the land manager (Irwin and Geoghegan 2001).

The Thünian model is thus viewed here as providing a conceptual structure capable of connecting broader scale structural changes to location rents and farm level microeconomic decisions, and arranging the outcomes within a specifically spatial landscape. This conceptual model extends to both of the principal objectives of this research, namely understanding the migration processes through individual, farm level utilities and extrapolating impacts across a landscape. Just as capital and other resources are viewed as being redistributed across a landscape, so too are people, who move to where their skills are in the highest demand.

With the basic structure and conceptual model now in place, this chapter proceeds to a more formalized description of the rent model. In doing so, it also considers concepts of marginality and linkages between land use area and location. This leads to the application of the rent based model to consideration of indirect land use change. In the process, I unpack indirect land use change into supply adjustment and investment effects, the latter of which leads to the formulation of a location-utility model, where mobile agents' utility maximization is framed within a spatially diverse structure of location rents.

4.1 Marginality, Land Rents and Location

This research assumes that landowners, or those that otherwise control land, employ their parcels with an aim of maximizing their utility, given the specific set of constraints or advantages peculiar to both land and person. Such a set of constraints or advantages may include biophysical attributes of land, access, and availability of resources, including the skills, capital and knowledge required for production. For simplicity, in the present case utility is considered to be a function of land rents, or the difference between the value of outputs harvested, *PQ* (the value out the product output, *P*, by the quantity of output produced, *Q*) and the total cost of inputs employed, *CI* (*C*, the cost of inputs, by the quantity of inputs required, *I*), as framed in equation 4.1. Here, land owners seek to maximize the net present value of potential profits, or rents, *R*, over a working time horizon, *H*, by choosing from multiple possible land uses, *K* (*K: s,k*, e.g. s = soybeans, k =cattle) at time, *T*. Rents for a given year (for cattle) in location l are thus written as:

$$\boldsymbol{R_{kl,T}} = (\boldsymbol{P_{lk,T}Q_{lk,T}} - \boldsymbol{C_{lk,T}I_{lk,T}}) \qquad 4.1$$

Marginality, in the present context, occurs where land rents for a given production strategy are zero or potentially negative, dis-incentivizing market-based production.

In a single product, non-spatial model where the rent maximizing producer considers land quality exclusively in his or her decisions he or she will choose to occupy the most fertile lands first. Such an agent would leave the less fertile lands, which generate comparatively less or even negative rents, fallow or otherwise in an unproductive state (when potential rents are zero or less). In a two land use model, more intensive activities (e.g., soybean production) occupy the most favorable lands while less intensive land uses (such as cattle) are relegated to those areas considered less fertile.[6] The model is dynamic, and as rents for one product rise production

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[6] Intensification refers to an increase in the ratio of capital investment to land Both cattle rearing and soybean production are land extensive operations, each utilizing enormous land areas per unit of worker and invested capital. However, soybean production is considered to

would progressively expand into areas of slightly lower rent generation, continuing until all lands that maximize the rents associated with the given land use are exhausted. This implies that an expansion of the more intensive product would come largely at the expense in area of the less intensive product, an effect which would trigger a loss in supply for the good and a potential expansion in its own right (as will be explained in greater detail in the following section). It is important to note that this (Ricardian) model of land quality and marginality as described so far is aspatial, with changing rents affect the distribution of land uses according to a cascading scale of land quality, rather than relative location and access.

Within the Amazon Basin, some have famously suggested that the region's longstanding economic marginality is a product of its the acidic soils, which supposedly impeded agricultural productivity and development (Meggers 1971). Though this thesis appears to be by now well overturned, arguments have persisted that the Amazon's land quality may be inadequate to sustain production in some areas of the basin, particularly in the western Amazon where heavy precipitation is recurrent (Chomitz and Thomas 2003). However, if some have pointed to supposedly unfavorable physical conditions to explain lack of production growth in the region, recently it has become increasingly recognized that the Amazon, with its planar topography, predictable rains and year round growing season, is highly favorable for production (Walker et al. 2009a). The obstacles that currently impede production in the region, per this latter perspective, have been based on another concept of marginality, namely one tied to access.

Given its privileging of access and spatial relationships, the Thünian model, which distributes land uses according to not only fertility or land suitability, but also according to the

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be an intensive land use when compared to cattle production, with higher per unit costs in both capital and labor per unit of land than beef production. A land use change from pasture to agriculture is thus viewed as a form of intensification.

cost of transporting goods and services to and from the farm gate to the market, has been employed in conceptualizing land use change in the Brazilian Amazon. The Thünian model is famously, or infamously, often illustrated by a theoretical, featureless plain dominated by a single market around which a series of concentric land use rings align, with more intensive land uses capable of generating higher rents per unit of land situated closer to the place of consumption, and progressively more extensive land uses constituting themselves in comparatively more spatially marginal locations (Walker et al. 2009b, Angelsen 2007, Geoghegan et al. 2001). At some distance from the market production is no longer profitable, the rent margin is zero, and agriculture or other land uses cease, eventually giving way to the so called fringe areas or the uncultivated wilderness (Walker 2001). Land prices across this landscape vary according to their potential to generate rents, with prices being higher in areas immediate to the central market point but decreasing with distance, or as more intensive land uses give way to less intensive ones.

I can formulate the Thünian land use model (eq. 4.2) by including *t*, transportation costs, which vary according to land use and distance (*d*), to equation 4.1.

$$\boldsymbol{R_{kl,T} = (P_{lk,T}Q_{lk,T} - C_{lk,T}I_{lk,T} - dt_{lk,T})} \qquad \textbf{(4.2)}$$

As with a land quality based model, the Thünian formulation places more intensive land uses on the most desired land while less intensive land uses are relegated to less favorable conditions; here, however, the spatial location is explicitly included. The Thünian model is particularly useful as a mechanism by which to consider spatially explicit land use frontiers, or locations where potential rents for two or more land uses are at equilibrium. These economic frontiers, or points of land use transition, are by no means static, but rather expand or contract with changes in economic rents, i.e., with changes in product prices, yields, or input and transportation costs. A positive increase in rents for the more intensive production strategy will act to push the production frontier outward and further from the market center, meaning that areas of the less intensive production strategy may be converted to those of the more intensive one (Dunn 1967).

4.2 Rent Theory and Indirect Land Use Change

The Thünian model provides a particularly useful heuristic with which to consider how market adjustments broadly impact not only a particular land use in a single location, but also lands in other, potentially distant locations. In a one-product world where beef were the only agricultural commodity produced, a Thünian description of the deforestation process would be a matter of identifying conditions leading to increased rents for ranching and estimating the area response as increased prices for beef or transportation cost reductions would bring lands into production that previously would not have generated rents (Richards 2012, Angelsen 2007, Walker and Solecki 2004, Walker et al. 2009a, Walker 2001). The addition of a second land use, however, complicates the model. It brings into play a second frontier, namely an intensive frontier where the intensive product displaces the more extensive one. In the case of soybeans and beef, where soybean production is positioned closer to markets and beef production is positioned at greater distances, the intensive frontier occurs where croplands occupy existing pastures, while the extensive frontier occurs where beef production expands at the expense of forest. In this model rising rents for beef production would activate the extensive frontier, incurring a loss of forest area, but with only a minimal impact imparted on croplands. Alternatively, if economic conditions favored soybeans, croplands would encroach into pastures until all are exhausted, and at which point the soybean frontier becomes the proximate cause of deforestation. Of course, these circumstances do not match the Amazonian case, in part because the market situation and other factors have mostly sustained strong rents for both beef and soybean production. However, the movement of the intensive and extensive frontiers can be linked, suggesting that the extension of the intensive frontier will contribute, indirectly, to the expansion of an extensive frontier. At first glance, the model is closely related to broader scale partial or general equilibrium models; however, at the same time it positions land use changes within a spatially explicit landscape, which is essential in this analysis.

As rents for soybean production in the Amazon evolve, two land cover change processes occur. The first is intensification, where rents for agriculture exceed those of ranching, and lesser intensive grazing lands are converted into more intensive production practices (such as agriculture). The second process, and the one of great interest to current considerations of ILUC and carbon accounting, is that the initial loss of pasture indirectly leads to the reconstitution of beef operations in more marginal lands, potentially at the expense of natural land covers (Walker 2011b, Walker et al. 2009b, Walker et al. 2009a).

The parallel movements of the soybean and cattle sectors are viewed here as linked through a two tiered spatial effect, where dual expansions are due not only to similar responses to favorable economic conditions for both goods, but also to an aspatial supply adjustment effect and an explicitly spatial investment effect. Whereas the former can be attributed to a partial loss in beef supply, the latter stems from capital gains reached by ranchers selling their appreciated properties and the spatial relocation of skills and capital tied to the industry. The investment effect, which assumes a prominent role in conceptualizing the objectives of this dissertation, brings the role of the farmer as the embodiment of the skills necessary for profitable production to the front and center of this research.

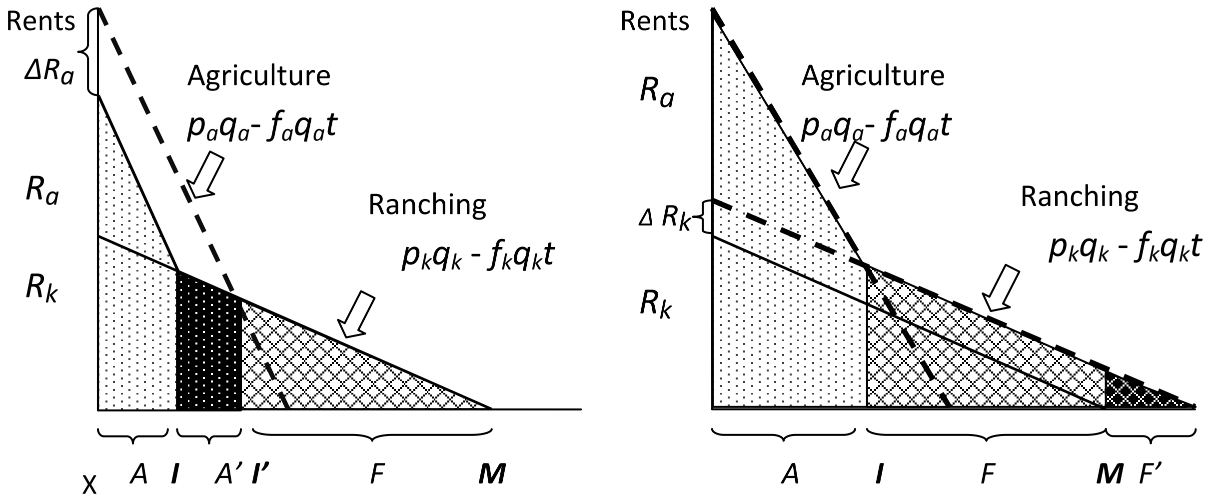
4.3 *The Indirect Effects*

Here I argue that the rent structure, in which multiple land use frontiers are linked by size and specific production locations, acts to link together the location and extent of agriculture and pasture areas. These frontiers are linked through two principal mechanisms: (1) a supply adjustment effect, where a loss in beef supply triggers a partial equilibrium response and a rise in rents for beef that results in new lands converted to pasture, and (2) an investment effect, where human and financial capital fixed to the ranching sector are displaced or dispelled to the frontier (Richards 2012). Both are considered here.

4.3.1 Supply adjustment effects and general or partial equilibriums

Many of the studies that form our understanding of indirect land use change stem from concerns over the potential indirect impacts of subsidies for corn and corn based ethanol production in the United States. This research has largely revolved around the concept that the diversion of cropland production from food to ethanol would require the creation of additional cropland areas to meet global food demands. Unfortunately, given constraints on available land and human capital suitable to production in the American Midwest in the United States (Swinton et al. 2011), new food production would need to be sourced from abroad. Potentially, this would include regions of carbon dense natural land covers in places such as Brazil or Indonesia (Fargione et al. 2008, Searchinger et al. 2008, Tyner et al. 2010b).

This supply adjustment effect can be illustrated within a Thünian framework. Consider again the earlier described economic landscape dominated by two principal production strategies, namely soybeans and pasture. Increased rents for soybean production results in the encroachment of croplands into pastures, implying a loss in pasture area and a decrease in beef production. Where beef supply is elastic with respect to beef prices this, in turn, would contribute to a rise in beef prices, which would render ranching viable in areas where previously it was not. The magnitude of the supply adjustment effect depends on the elasticity of global prices for the good in question, in this case beef, with respect to any losses in supply (Walker et al. 2011a). The process can be illustrated, as shown in figure panels 4.1a and 4.1b. The y-axis indicates the capacity for generating rents for each land use at a given distances from a market center; the x-axis represents distance from a central market. The curves labeled R_a and R_k represent rents for soybeans (a) and cattle (k), respectively. The cost of transporting soybeans is greater than the cost of transporting cattle, as indicated by the degree of incline of their respective rent curves. Given these conditions, at distance *I* rents for both products are equal, resulting in an intensive frontier, or where soybeans give way to agriculture. Where rents for cattle come to equal zero, at *M,* pastures give way to forest. In panel 4.1a an exogenous increase in rents for soy (ΔR_a) occurs, shifting *I* to *I'*, in the process converting areas of pasture to cropland but resulting in a loss in the quantity of land available for ranching (shown as *A'*). The loss in pasture area results in an increase in local prices for beef and thus an increase in rents for cattle production (ΔR_k). Raising rents, in turn, thus brings new lands into production (*F'*) and extends the forest frontier outward. This suggests that the expansion of an intensive good could trigger the expansion of the extensive good, assuming that the loss in area supply to the extensive good sufficiently impacts its price signal.



(a) Rise in Crop Rents and Conversion of Pasture to Cropland (A')

(b) Cropland Expansion and the Extension of the Margin of Production(F')

Figure 4.1. The Rent Curves of Von Thünen

While the general equilibrium or supply adjustment effect may be useful to estimate or explain broader global land use trends, the assumption in this dissertation is that, in the present case of soybeans and cattle in the Amazon any supply adjustment effect is likely minimal. This owes to two sets of factors. First, in the Amazon, local prices are moderated not only by global supplies and prices but by region or nation-specific variables such as trade agreements, disease controls, the exchange rate, infrastructure improvements and institutional changes; and it is unclear as to what extent global prices have driven the evolution of the Amazon soybean and ranching sectors. That global prices for beef and soybeans were actually falling during much of the early 2000s, when deforestation and cropland expansion were highest, suggests that incentives at the farm level may not necessarily be congruent with global prices or demands. Second, any change in global cattle prices with respect to possible supply losses tied to cropland expansion in the Amazon is also likely be minimal. For while the magnitude of the Amazon herd has indeed expanded to such a degree that a large loss in beef supplied from this region could impact global beef prices, such losses remain minimal in comparison to the overall supply of pasture. From 2001-2004 approximately 6,000 square kilometers of pasture were converted to cropland in Mato Grosso (Morton et al. 2006). Yet, according to the 2006 agricultural census, in Mato Grosso alone, pastures encompassed nearly 220,000 square kilometers state (IBGE 2006). Thus over a three year period, less than three percent of the state's pastures would have been ceded to agriculture. Given the minimal loss of supply area in comparison to global excess supplies for beef, any supply adjustment effect, if indeed one is occurring, is likely to be insignificant. Here I suggest that, given the specific organization of resources and land use in Brazil, another effect may be occurring; whereby increases in cropland area results in an increase in pasture areas. This is based on a spatially explicit mechanism that is here considered to be the principal driving factor behind indirect land use change in the Amazon.

4.3.2 Investment effects

The investment effect introduces another effect to the discussion on indirect land use change. Specifically, it shifts the focus to farm or agent level decisions, and to migration and investment dynamics occurring within the broader land use system. As indicated at the outset of this chapter, the presence of sufficient skills and capital is essential for any economic strategy to be perpetuated; and the spatial movement or dissemination of skilled labor is thus viewed as a critical component in land use change. The dissemination of land uses from areas already under production to more marginal lands is then theorized as driven, in part, by the migration or movement of the farmers and ranchers that perpetuate their respective land uses. However, just as land managers need incentives to alter their economic choices, so too are incentives needed to bring farmers and ranchers to alter their location (Sjaastad 1962). These incentives are ultimately found in the spatial differentiation of changing land prices and profits.

Before proceeding, it is essential to recognize the importance of producer welfare alongside profit or rent maximization as a basic component in any utility maximization function (Walker 2003, Singh, Squire and Strauss 1986, Ellis 1986), though for the purposes of the present model, household welfare and rent maximization are viewed as separable, with expected utility linked principally to expected profits (or rents). An independent, risk-neutral, land manager will thus attempt to maximize his or her expected utility, which is equal to the expectation of income. I view migration in this context as not only a vehicle for the movement of capital and skills, but also as a means of utility maximization.

Here, in my focus on migration as a component of indirect land use change, I draw on the initial mobility formulation by Sjaastad (1962) and the differentiation of returns on human capital, and suggest that as potential rents emerge in frontier regions human and capital resources will also flow accordingly. The Sjaastad model viewed migration as a function of potential individual returns and costs, and included both monetary (i.e., wage differential) and non monetary (i.e., learning a new skill, time lost searching for employment, loss of contact with friends or family) factors. The formulation considers the land manager to be an agent seeking to maximize his or her own individual utility through relocation. Implicit in this approach is an acknowledgement that human capital, as with other forms of capital, is subject to market demand and is liable to appreciation or depreciation (Sjaastad 1962). When and where the demand for a specific set of skills is altered by changing social or economic conditions, the value of those skills will rise or fall (Todaro 1980).

One of the innovations of this research is to situate the migration model of Sjaastad within the explicit spatial structure framed by the rent theory of von Thünen. Here, ranching and farming rents are thus viewed as functions of location, and the farmers and ranchers that possess the knowledge of how to reap these rents will migrate to regions where they may maximize the utility of their skills. Thus where rents for agriculture overtake those for frontier beef production, the demand for labor and capital specific to ranching will decrease; at the same time, however, it may be increasing for those possessing the knowledge and capital essential for agricultural production. For skilled workers seeking to maximize the utility of their skills and capital, the course of action may include disinvesting from one location and relocating, as remaining in the present location would carry a significant opportunity cost. This assumes, of course, that ranchers and farmers are endowed with use-specific skill sets that are not readily converted to fungible capital or new skill assets through divestiture. The key here is that skilled labor, as well as certain fixed capital inputs such as harvesting and planting machines, are specific to certain economic strategies, and are not necessarily transferable to other means of rent generation.

In the context of the Amazon case, ranchers possess a skill and network set specific to ranching, just as farmers possess a skill and network set specific to farming. Thus just as land may contain use-value in the form of structural improvements or other investments specific to a single land use (e.g., a grain silo is of little use to a frontier rancher), so too does the manager of that land, who possesses a set of fixed skills and experiences. Use specific skills increases the marginal productivity of land, essentially decreasing operation costs and risk and increasing yields, with the ultimate effect of maximizing rents, so long as the skills are dedicated to the production strategy to which they are prescribed. In this sense, skills are personal investments made by the land manager that increase the value of their work, but they are not necessarily transferable to other occupations. In addition to financial interests, there are also clear cultural ties that may bind people to their professions, whether as ranchers, smallholder, semi-autarkic farmers, or soybean producers (Adams 2008, Richards 2012).

As rents in a given location for agriculture exceed those of ranching, several processes occur that drive this investment effect. First, land prices for not only agriculture, but also pastures, will rise. This occurs when and where the net present value of future earnings attributed to a parcel of land increases as potential purchasers identify its possibility for being converted to a higher rent generating activity (e.g., soybean production). Second, soybean producers, perceiving that soybeans could profitably be produced on a rancher's parcel, will look to acquire his or her lands, whether through renting or purchase. As land prices for a parcel of pasture increase beyond the value likely to be reaped through ranching on the land, the rancher will identify the increasing opportunity costs of remaining at their location. He or she may choose to continue ranching, despite the change in potential rents and the opportunity costs of such a strategy. However, another conclusion may be reached, namely that the value of selling or renting the land to a farmer would allow the landowning rancher to capitalize the increased value of the land. The transfer of the given parcel from the rancher to the soybean farmer would constitute direct land use change and an immediate loss in area supply for the ranching sector; however, and more importantly, it also constitutes a transfer of capital from the soybean sector to the ranching sector. This investment effect does not only affect those displaced directly; rather as land prices rise with the demand for land new capital may be flooded into the region, also triggering land use change. In any case, the investment effect may carry a cascading impact across the Amazon landscape, as farmers and ranchers identify not only the present rent generating potential of a property, but also its future potential.

Ultimately, the decision to relocate thus becomes a function of access to land (as embodied, in the present case, in land values) and rent potential. In this scenario price differentiation between potential points of displacement and potential destination locations emerges as a key factor driving both ranchers and farmers. The capital gains associated with selling or renting appreciated land assets at the point of origin facilitates the spatial redistribution of capital associated with both a particular agent and an industry by breaking down a principal economic constraint, namely access to capital in relation to land at the frontier. In effect, the pairing of financial capital with use-fixed human capital results in the simultaneous spatial redistribution of these resources during the migration process.

In addition to providing a regional element to indirect land use change, the investment effect theorized here links migration to variation in farm level incentives over a landscape. In doing so, it explicitly breaks from the implicit assumption that location is fixed while land use is not. I note, for example, that work in land economics (e.g Lubowski et al. 2008, Hardie and Parks 1997) often is premised on the assumption that the land manager is spatially fixed but economically mobile, e.g. capable of modifying their production strategy to suit changing economic conditions. While this indeed may be the case in the long established agricultural regions of the American Midwest, where farmers rotate between a stable of staple crops or reside on third or fourth generation farmsteads, I argue that, in Brazil's Amazon frontier, it is often the case that land managers are flexible in mobility but not in production strategy. The present research adopts a perspective that is reflective of this reality and suggests rather that the land manager is spatially mobile, but fixed in his or her occupation.[7]

[7] It is unclear whether this position has been explicitly adopted in previous research. I know of no examples where it has been put forward, though it has been implied on numerous occasions by researchers studying the movement of smallholder farmers.

The spatial trajectory of the land manager who chooses to sell his or her land is thus of great importance to this research, as the chosen trajectory carries the potential consequence of dispelling resources – and land uses- from a point of origin to a potentially distant destination. For clarity, I distill the trajectory of a landowner who has sold a parcel into three principal categories: (a) relocation, (b) retraining, and (c) retiring (Richards 2012). Indirect land use change occurs when and where ranchers or farmers decide to relocate, or through the spatial redistribution of their skills and capital to new locations.

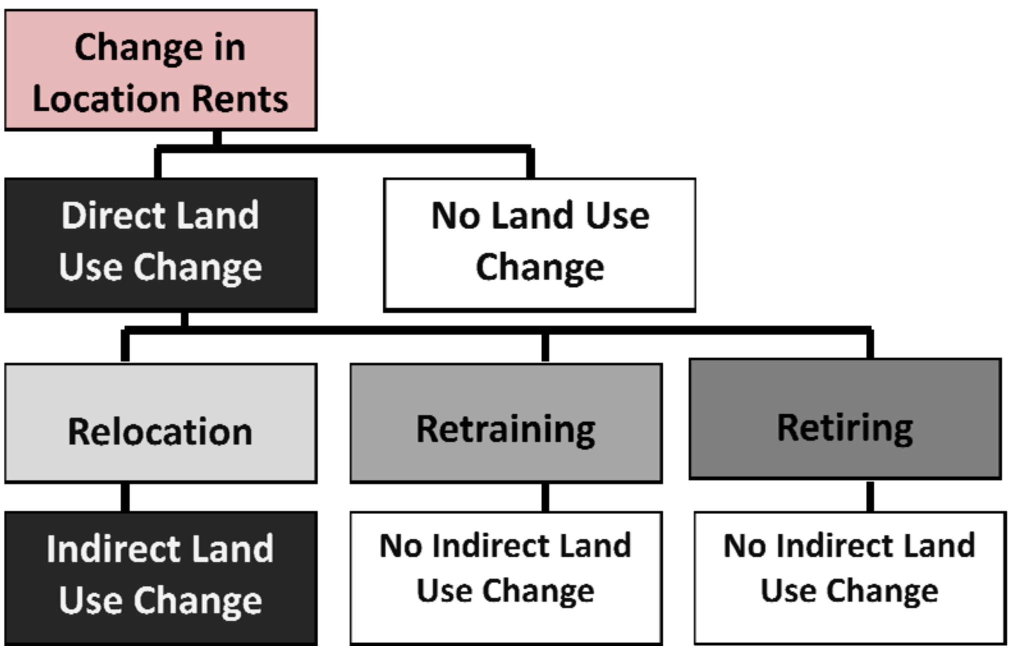


Figure 4.2
Displacement or investment options and the indirect effect

(a) ***Relocation.*** Implicit in relocation are two sub-processes, namely the capital gains reaped by the seller and the relocation of the essential skills and capital required to establish production. Given disparity in land prices between the point of land sold and the point of land acquired, the seller can increase their area of production through relocation. Equally important to expansion is the spatial redistribution of skills and capital. Without knowledge of how to use land other than for forest, there is little incentive to clear the forest. Migrating ranchers (and in some cases farmers) who sell their properties and relocate to the frontier provide this knowledge, and thus import the knowledge with which the potential profits of a forest cleared exceed those of a forest standing. Migration also constitutes the link that connects spatially distant changes in land use, with the increased demand for land that comes with new migration resulting in higher land values for landowners in the region receiving new migrants.

It is important to observe that, historically, Amazon development in Brazil has been impeded by shortages of human and financial capital in the region. Land here has long been in abundant supply while skilled labor and investment capital are comparatively scarce. Over past decades, however, the migration of farmers and ranchers and the development of these skills in the region have increased their abundance.

(b) *Retraining.* Retraining, in the present context, refers to the acquisition or development of the skill set necessary for a new production strategy. As potential rents derived from soybean production grow to exceed those of cattle rearing, a rancher may decide to alter his or her economic strategy to take advantage of these opportunities. Retraining carries no indirect effect, as there is no spatial displacement of skills or capital. There are several impediments, however, that a rancher intending to convert a significant portion of the operation to farming is likely to face. First, the cost of retraining or of acquiring the skills necessary to shift from beef to soy production may be substantial, and ranchers may be unwilling to unilaterally shoulder the uncertainty associated with taking on comparatively risky agricultural activities. Second, converting a field from pasture to soybeans requires a significant investment in capital to clean the parcel of any remaining forest debris, till the soils, correct ph levels and fertilize and, if needed, construct bunds. These costs would be in addition to the cost of purchasing seed, machinery, and hiring skilled farm hands. Financing the conversion may be problematic, given that such a conversion would need to take place without the capital transfer that might be accrued by selling land. Finally, it must also be observed that commodity farming and ranching cultures in the Brazilian Amazon are distinct, and cultural ties may dissuade crossover from one profession to another. For younger ranchers, or for the sons or daughters of ranch owners with longer employment horizons, however, the incentive to retrain may pose a particularly attractive option.

(c) *Retiring*. The final option shown in figure 4.2, retiring, refers to those individuals who, after deciding to sell or rent their land, cease rural economic activities. This includes not only retirement in the traditional sense, but also those individuals who, after relinquishing their control over a parcel of land, pursue work in a non-land based industry, or cease work entirely. Thus spouses who sell the land of a deceased husband, or former ranchers who have left the ranching sector to invest in another economic activity, whether a car dealership, a veterinary shop, or a hotel, would all fall into the category of retirement. There is no indirect or investment effect associated with producer retirement, as the skills embodied by the individual are not only not relocated spatially, but are effectively removed from the sector in question.

The investment effect outlined here, as conveyed through the relocation of essential skills and capital, is of principal interest to this dissertation. I provide an explicitly spatial linkage by which to tie together distant changes in land use and formulate an economic landscape whereby production changes in one location are tied to production changes in other, potentially distant locations through the movement of an agent, albeit within a structure of economic incentives. In this sense, it considers migration to be an economic decision where capital embodied in the land manager is redistributed across an economic landscape to where it may maximize its utility. The investment effect is formalized within what I refer to here as a location utility model.

4.3 The Location Utility Model

At this stage, I can now formalize a conceptual model of the underlying behavioral elements to the displacement effect. Here, both ranchers and farmers are conceived as risk neutral and price taking agents. They are invested with a use-specific skills set and will choose to maximize their utility by choosing the production strategy and location that best maximizes their skills and capital. Potential locations are restricted to an origin and destination, for the sake of simplicity. The rancher considers mobility options on the basis of (1) the net present value of future rents (*R*) for economic strategies *K*, (*K*: *a*= farming, *k = cattle, r = retire*), discounted over a suitable time horizon at locations *L* (*L:* o = origin, d= destination); (2) the values of lands sold or purchased at the origin and destination locations (V_o, V_d); (3) any costs incurred through relocation (C_{od}); (4) costs associated with use conversion on the present parcel ($C_{o,ak}$); and (5), costs incurred through the process of the land manager retraining for a second land use ($H_{o,ak}$).

Naturally, a number of these variables will vary over a spectrum of potential ranchers and farmers. Variation in age and working time horizon, educational background and personal ties to certain locations, for example, will not only affect any utility associated with possible relocation, but will also may result in an abatement or increase in costs associated with possible retraining. . When the difference between land prices at points of origin and points of destination increases, so too, often does distance between these points increase, which implies that both less information is likely to be available to the purchaser and higher possible costs associated with relocation.

With this simplified structure now in place, the utility of income may be expressed as:

$$U(X_{K,L,T}) \qquad (4.3)$$

where U is utility of the land manager's (i.e., the farmer or the rancher) total income, X, at potential locations L for land uses K, or $X_{K,\ L}$. Income, X, can then be stated according to various combinations of land uses and locations (equations 4.4-4. 7).

For remaining: $$X_{k,o} = R_{k,o} \qquad (4.4)$$

For relocation: $$X_{k,d} = R_{k,d} + V_o - V_d - C_{od} \qquad (4.5)$$

For retraining: $$X_{s,o} = R_{s,o} - C_{o,sk} - H_{o,sk} \qquad (4.6)$$

For retiring: $$X_r = R_r + V_o \qquad (4.7)$$

Decisions regarding whether to relocate are thus governed by the rule to move, if and only if

$$U\left(X_{k,d}\right) > U(X_{k,o}) \qquad (4.8)$$

And

$$U\left(X_{k,d}\right) > U(X_{s,o}) \qquad (4.9)$$

And

$$U\left(X_{k,d}\right) > U(X_r) \qquad (4.10)$$

The Thunian rent structure enters into this model via two channels: first, with the stream of expected benefits, R, and second, in regard to land values, given that increases in land values themselves are endogenous to the expected stream of net benefits. Incentives for relocation, and hence for possible indirect land use change, enter into $X_{K,L}$ via V_o. Because values for V are determined not only by the future stream of rents for pasture, but also other factors driving the market for land, including rents associated with soybean production, the soybean sector occupies a role in this utility determination. This model also calls attention to the attachment of land managers to their specific production strategies. If costs of retraining are prohibitively high, few ranchers are likely to convert to agricultural production strategies, steering more skilled labor toward new locations. Variations in land values for large tracts of available land, combined with increased access and rapid appreciation, are likely to favor $U\,(X_{k,d})$ over alternative transition pathways of remaining, retiring, or retraining.

Indirect land use change is ultimately linked to the relocation premise described in equations 4.8-4.11, though relocation in and of itself does not imply land indirect land use change, as ranchers may seek to relocate to existing ranchlands rather than forest areas. However, new incentives for relocation, even from one pasture to another, are likely to impact land values across a broader region by increasing the demand for land and trigger further land use change at the frontier.

The location-utility model places its emphasis on migration and the movement of skills over a broader landscape, and provides the underlying basis for both objectives one and two of this dissertation. I have designed the model to place agent or farm level decisions within a land use structure built on location rents. With the theoretical model in place, the following chapter considers the net impacts of indirect land use change derived from expanding soybean production in Brazil on forest cover in the Brazilian Amazon.

CHAPTER V

ESTIMATING INDIRECT LAND USE CHANGE

This chapter addresses the first objective of this dissertation. Specifically, it provides an empirical estimation of the indirect impacts of soybean production. It begins with a review of econometric applications to deforestation by both land economists and land change scientists. This review gives shape to the general approach of the chapter and leads to the development of the spatial modeling framework used in the analysis. The field of spatial econometrics, in particular, assumes a critical role and is addressed in some detail. This leads immediately to a description of the spatial durbin model (SDM), which, following work by Arima, et al (2011), has been adapted for the aims and specificities of this analysis. After laying out the general model used in the analysis, the chapter then offers a detailed description of the data used and the weights matrices employed to distribute the indirect effects across a spatially explicit landscape. It then proceeds to a specification of the model and a brief discussion of the results. The chapter concludes by arguing that an indirect effect can be estimated, and that the effects are both significant and substantial.

5.1. Land Economics and Land Change Science: Econometric Estimations of Land Use Change

Researchers have long employed econometric methods in economic studies of land use and to better understand the underlying drivers of environmental and economic changes (Tyner et al. 2010b, Pontius et al. 2007, Plantinga and Miller 2001, Geoghegan et al. 2001, Antle and

Capalbo 2001, Nelson and Hellerstein 1997). Many of the methods and concepts upon which these studies have been founded stem from land and resource economics, particularly those concerning estimations of area supply responses and agricultural intensification. In this section I consider several of these approaches to modeling and use. I focus on four often overlapping tracks of analysis: (a) land economics; (b) household and farm level analysis; (c) region scale land use analyses; and (d) origin-destination models, which have largely focused on migration. This dissertation (and this chapter specifically) draws from each of these sub-topics, choosing concepts selectively from each. As will be described, it borrows concepts of utility maximization from subtopics a-c, while incorporating the interregional linkages that are prevalent in origin-destination models (sub-topic d).

This section is by no means intended to comprise a full review of the methods and results of past econometric models of forest loss and land use change in tropical regions. It is intended, rather, to situate the present chapter within the context of several conceptual frameworks and to acknowledge a series of influential antecedents. These antecedent models have ranged widely in both scale and geographic location, as well as method of analysis; combined, they implicate a broad array of driving forces and spatial effects underlying land change processes.[8]

5.1.1 Land Economics

In many of the studies of land use born from land economics, land is viewed as a limited resource employed by land managers in the pursuit of utility maximization or economic returns (Lubowski et al. 2008, Plantinga and Miller 2001, Hardie et al. 2000, Adams et al. 1999). From

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[8] A broader review of the conceptual foundations of this work, much of which is ultimately derived from applied economics can be found by Kaimowitz and Angelsen Kaimowitz, D. & A. Angelsen. 1998. *Economic Models of Tropical Deforestation A Review*. CIFOR.. These models have ranged widely in both scale and geographic location, and have implicated a broad array of driving forces underlying the process.

this neoclassical perspective land use is an artifact of the land manager, who presumably considers a suite of potential production strategies and adopts whichever strategy offers the highest returns. Lubowski, et al (2008), in their recent and widely hailed article on what drives land use change in the United States, for example, suggest that broader scale changes in land use across the United States are closely tied to changing returns for possible production options and public directives. This model builds on an extensive body of past work by land economists in two key regards: first, it adopts a perspective where land use change is viewed as a partial adjustment to expected returns; and, second, it incorporates diversity in biophysical attributes.

The first of these concepts, namely the partial adjustment approach to estimating cropland elasticities, was first put forth in Nerlove's (1956) seminal article conceptualizing land use change as a function of expected returns and past areas in production. Land managers, per this perspective, adapt to changing economic rents by adjusting their areas of production according to expected returns and constraints on resources access. Given that expected returns are dependent partially on the returns from past years, recent market dynamics or returns are only partial determinants of area responses. Nerlove addressed this temporal dependency by including temporally lagged observations of cropland areas. The approach has since been widely adopted in time series analysis of production areas and has been used extensively in the calculation of area elasticities with respect to price adjustments (e.g. Askari and Cummings 1977, Lin et al. 2000, Hausman 2012).

A second conceptual factor that has come to dominate much of the work on land use change from the field of land economics is the incorporation of differences in land quality. Land managers are constrained by the attributes of the land that they possess, and each landowner faces a unique set of potential returns to their land, with certain crops proving more profitable in some regions, but less so in others. Land economists have incorporated land quality into their econometric analyses of land use change through a number of different mechanisms. Palmquist (1989), for example, approached the issue by considering land quality as a differentiable factor of production and using hedonic models to estimate welfare effects associated with land qualities. By breaking down land quality into a continuous vector of favorability for production, he enabled the inclusion of land attributes into his estimations. A similar approach was taken by Lichtenberg (1989), who conceptualized land quality and capacity not as a continuous vector, but as an attribute bundle. Whereas some attributes were mutable, such as fencing and central pivot irrigation (the focus of his article), others were immutable, such as sunlight and topography. In line with the Ricardian theoretical positioning, this work has broadly been suggestive of a land use pattern where the highest quality land (whether created through human intervention or through nature) was employed for more intensive production strategies. More intensively produced goods generating higher returns occupied the most fertile lands, while less intensive goods occupied lands of lesser quality. As rents evolved, lands of lesser quality were, in some cases, altered to increase their production capacity through investments in irrigation or fencing. Any decision to improve land quality, per this framework, becomes a function of not only the cost of the improvement, but also of the value of the potential crop.

This work was followed by Orazem and Miranowski (1994) who constructed their own rent model dependent upon not only market returns for potential crop choices, but also the specific potential and capacity of regional soil types. Hardie and Parks (1997), who used an area base models to estimate the distribution of land use in the southeastern United States, reiterated the importance of considering land quality, which, when taken into account in a rent maximization model, increased the accuracy of supply area responses. However, still other work suggested that while a rent based approach provides a useful analytical framework, it must also be recognized that land managers face significant, personal constraints in their decisions. A lack of access to the technological necessities required to change a land use or capital to finance a potential conversion, and longstanding habits of production, for example, may mitigate potential changes in land use; additionally, the perception that some land use changes (such as letting land revert to forest for timber production) may be irreversible dissuades risk averse landowners from pursuing potentially more profitable alternative land use strategies (Parks 1995). This latter recognition is in basic agreement with the general theoretical approach of this dissertation, where land managers are invested with a specific set of skills and capital, and may be averse to altering their land use, despite the potential opportunity cost of not doing so.

Implicit in much of this work is the concept of marginality. Marginal lands are effectively the last area unit put into production or, within the present context, the land of the lowest quality (Ricardo 1891) or least accessible (von Thünen 1966) used in the production of a certain crop (Peterson and Galbraith 1932). In the research presented in this sub-section, I view marginality as a function of land quality and changing production rents; and where returns for production strategies rise or fall land areas will either be incorporated into the production system or recede into disuse. The concept of marginality is particularly useful for framing the advancement of the economic frontier in the Brazilian Amazon, where in recent years rising prices for soybeans and beef have contributed to the expansion of an agro-pastoral expansion. As will be shown in the ensuing sections, however, and as was discussed at length already in the earlier chapters, marginality in the Brazilian Amazon has in recent years been viewed as a function not of land quality, but of access (Walker et al. 2009a).

5.1.2 Household models of deforestation

The utility maximization framework that has served as the basis for much of the work in land economics also constitutes the foundations of econometric work by cultural ecologists in studies of household or farm level land use. Much of this work draws inspiration from the soviet agrarian economist, Alexander Chayanov, who observed that households seek to not only reap the highest returns on their land, but to balance their available labor and consumption needs with a desire for leisure. He viewed household decisions as a function of labor resources and household food demands, with land uses evolving with the needs and structure of the family. As households grow or decline in number, observed Chayanov, so too does the available labor pool and the need for production, which requires additional land. Chayanov's theories of household economics led directly to work on peasant economics, which emerged in the influential development literature of the 1980s. The approach was formalized by both Ellis (1986) and Singh, Squire, and Strauss (1986) and has since been widely applied to household studies of land use change, including in the Amazon.

The theoretical positions that underlie studies on peasant or household economics were broadly employed by the land change science community across the Amazon in the 1990s and early 2000s, where rapidly increasing smallholder settlements were seen as driving significant land use changes in the region. This was further advanced by Walker and Homma (1996), Pichón (1997), and McCracken, et al. (1999), who provided some of the initial econometric applications of household production analyses and lifecycle theories to the Amazon. In 2003, Walker advanced the household framework approach by instituting a two-tiered separable model describing farmer transitions from a household or peasant economy into a commercial, market oriented strategy of production. Collectively, this work has suggested that familial demands for land, as well as the availability of labor, provide both the means and the incentives for smallholder farmers to open new lands for production (Walker 2004) and to shift their production strategies between annuals, perennials, and cattle (Walker et al. 2000). This perspective has been advanced and merged with a market based approach, in part, by situating households within a spatial structure recognizing differences in access and transportation costs and a decision framework that transitions from welfare to rent based incentive structures (Walker et al. 2002, Walker 2003).

Other household level econometric studies across Latin America have examined the relationships between land use and variables such as farm size and available labor, and a variety of other economic, demographic, and social factors. In work in Central America, ethnicity or contact with NGOs (Carr 2005), as well as education and the biophysical attributes tied to a household's specific plot (Geoghegan et al. 2001), for example, have been linked to household land use decisions. Other, more recent econometric work in the Brazilian Amazon, which is critical to this analysis, are findings that access to capital (Caldas et al. 2007, Walker et al. 2000, Almeida and Campari 1995) and the mobility of resources have had an important impact on household level clearings. Migration (e.g. Rudel et al. 2002, Caviglia-Harris et al. 2012) and transportation costs have featured prominently in these analyses, and have been widely cited as an important factor underlying household level land use changes occurring in the tropics (Almeida and Campari 1995, Pichon 1997, Carr 2005, Carr 2009).

5.1.3. Regional scale and location-based models of land use change

While many of the econometric studies on land use in the Amazon have focused on household level processes, in recent years a trend has emerged that has shifted focus toward measuring the broader, regional scale responses to national and international economic shifts and market dynamics. The linkage between farm level processes and economic incentives in the Amazon has likely never been clearer than in the present age, as transportation costs decline and improved conduits for internationally consumed commodities connect the region to global markets. The rent model associated with von Thünen has often appeared, whether implicitly or explicitly, in the theoretical underpinnings in many of these applications.

Explicit examples of the application of rent theory to regional scale work in the Brazilian Amazon includes research by Vera-Diaz, et al. (2008), who developed a basin-wide rent model based on access and potential yields for soybean production and broader scale, political economic work by Walker (2009a) and Walker, et al.(2009b) . Similar rent based approaches to understanding regional land use change and intensification in the Brazilian Amazon have also become common in recent years (Mann et al. 2010, Bowman et al. 2012).

Other region scale econometric models of land use change in the Amazon have focused on area supply responses for soybeans. Notably, Barr, et al (2011) suggested that while soybean producers respond rapidly to positive changes in price, they are less inclined to take areas out of production after a price decrease. The reluctance to remove land from production during unproductive years is likely a residual of the heavy investment costs associated with rendering agricultural land suitable for production and transferring capital from one sector to another (Johnson and Quance 1972), as well as expectations derived not only from a past year but from a potentially much larger career horizon. Richards, et al (2012), in their examination of the regional and national responses in soybean area to currency exchanges, indicated that the elasticity of production in the Brazil's Legal Amazon region with respect to price is higher than elsewhere in Brazil. Broader scale econometric models carried out at the regional or national level also offer a means by which to extrapolate spatially explicit variables as a factor in production, as will be addressed in the ensuing subsections.

5.1.4. Migration and the inter-regional movement of people and resources

Migration comprises an important conceptual role in the positioning of the present chapter and in the dissertation at large. As has been described in the previous chapters, indirect land use change is conceptualized as occurring, in part, through migration and the spatial redistribution of capital, whether in human and social or pecuniary form. Much has been written on migration as a driver of land use change, particularly in the Brazilian Amazon, where migration during the past decades has brought new sources of both labor and capital to the region (Almeida and Campari 1995, Sawyer 1984, Caviglia-Harris et al. 2012, Perz 2002). Among others, the prolific Amazon scholar Phillip Fearnside has written extensively on the impacts of landless migrants and their roles as land clearing agents (Fearnside 2008). Some have identified the movement of farmers and ranchers from the southern states into central Rondônia as a key element in the region's colonization (Caviglia-Harris et al. 2012). Others such as Anderson, et al (2002), have suggested through econometric analyses that the role of migrant capital, and specifically, the levels of wealth present at migrants' points of origin, serves as an important predictive factor underlying land use change. This body of work provides an important block to the conceptual foundations to this work, with its recognition of the importance of migration as a driver of land use change.

Econometric estimations of the impacts of migration have largely focused on assessing the broader economic impacts of population mobility. From early work on migration by development economists, much of this research has focused on rural to urban migration, or on the broader economic impacts associated with the movement of people (Lewis 1954, Todaro

1980, Isard 1956). Recent econometric estimations of the impacts and drivers of migration have likewise tended to focus on macroeconomic effects stemming from the redistribution of capital across nations or to urban areas. Greenwood, in a seminal study on the effect of immigration on unemployment and earnings in Mexico, suggested that migration was essential to that nation's development process (Greenwood 1978). Somewhat more recently, Walker, Ellis, and Barff, (1992), employ a system of equations with joint dependent variables to evaluate the impacts of migration on both blue and white collar wages in the United States. Though comparatively rare, some recent work has examined rural-rural migration as it concerns out migration from frontier areas (Barbieri, Carr and Bilsborrow 2009, Caviglia-Harris et al. 2012).

A sub-section of the literature on migration has employed statistical methods to consider migration as a function of two sets of spatial conditions. For Clark and Ballard (1980), this process was better theorized as a two step decision, beginning with the decision by an individual to migrate and followed by considerations of then where exactly to migrate to. These authors then predicted migration through a system of two equations: first, a time series model capable of estimating the factors driving out migration; and second, a gravity model to estimate attraction based on a series of pull factors and their relative strength in comparison to the point of departure.

Other researchers studying migration have examined the relationship between relative pull and push conditions for multiple locations by borrowing the gravity model from the field of international trade economics. The gravity model, first popularized in the 1950s, estimated flows between locations as a function of the attributes observed at both potential origin and destination locations and of a measurement of separation (Porojan 2001). Despite the importance of separation or distance as a component in the gravity model (and in the general flow of any resources, for that matter) spatial approaches to migration have been infrequent (Cushing and Poot 2004), with work by Lesage and Pace (2008) offering one of the few exceptions.

The present work, conceptually, draws much from the origin-destination framework developed in the literature on migration and resource flows. However, it breaks from this literature in several important regards. First, rather than considering migration as a process of farm labor leaving rural areas or as a process mainly involving unskilled labor with low or minimal marginal value, it considers rural to rural migration as the spatial redistribution of valuable resources (both in human and financial form) across a landscape organized according to land rents and production possibilities. Second, it employs an innovative spatial approach to predict and distribute land use effects. As will be described in the ensuing sections, the indirect effects associated with land use change are distributed between origins and destinations through the weighting process associated with spatial econometric methods.

5.1.5. Antecedents

The past four sub-sections have touched on several threads of the literature that have influenced the approach taken in this chapter. The utility maximization principles associated with the fields of both household and land economics, for example, have been integrated into the conceptual framework at hand and set within a broader rent-based landscape structure. I situate this work upon the assumption that the farm level processes and incentive structures that underlie micro-scale land use change will be visible at the regional scale. I also draw on concepts of migration and resource flows as a basis from which to theorize the distribution of resources across space. While I do not adopt the gravity model in the analysis, I do adopted the generalized principles of distributing resources flows over a landscape (which in this case is viewed as a template of potential land creation) where utility maximizing individuals seek to minimize their opportunity costs. Ultimately, the waxing or decline of market returns thus implies a shift in regional production equilibriums, where resources are redistributed spatially, and from which a broader, indirect effect may be conceptualized and estimated.

To link together potentially distant locations, I employ a set of tools from spatial econometrics. In this chapter I now turn to consider developments within this subfield, as well as their role in shaping the approach I adopt for this research.

5.2. Spatial Econometrics

The development of new GIS and spatial analytic tools has brought a new dimension to econometric analyses. Conceptually, much of this work has focused on understanding the spatial patterns and spatially based equilibriums of land use. This stems partly from the realization that *where* a change takes place is often as or even more important than *how much* change occurs.

Spatial approaches to modeling land use change include (1) models based on spatially explicit data, using spatially-specific attributes and (2) spatial econometric models, deploying the techniques commonly associated with the models of Anselin (1988) and Lesage and Pace (Lesage and Pace 2009). The former category includes several notable efforts to model tropical deforestation. In particular, articles linking the expansion of infrastructure with deforestation, for example, have drawn attention to spatial issues (Pfaff 1999, Chomitz and Gray 1996, Nelson and Hellerstein 1997, Kaimowitz et al. 2002, Mertens et al. 2002, Soares-Filho et al. 2004, Weinhold and Reis 2008). In other, similar work in the 1990s, Geoghegan, Wainger, and Bockstael (1997) and Bockstael (1996) succeeded in integrating tools capable of capturing sources of spatial biases into their analyses of land values in the Pawtuxet watershed. By using spatially explicit data they estimated land values as not only a function of a specific set of local attributes, but also as a product of relative location. In effect, they suggested that value emerged not only from the attributes of a specific parcel of observation, but also from the values of nearby parcels. The approach that researchers have taken in this work resembles the spatial variation of the temporal accounting implicit in partial adjustment models, or where agricultural areas reflect not only the conditions for a single year, but also those of past years. The rent theory of von Thünen is recurrent throughout much of this work, though it is often more implicit than directly acknowledged.

The set of tools designed to capture the so-called spatial effects that are otherwise unobserved in standard econometric analysis constitutes the second spatial approach mentioned at the outset of this section. As location explicit data becomes increasingly available through new techniques in data collection and the advent and growth of GIS applications, the awareness of a so-called spatial effect, as well as the means by which to account for spatial biases, has increased dramatically. Just as econometric research has grappled in past decades with issues endogenous to time series research, including temporal autocorrelation and expectations based on historical precedent, so too has it now come to engage with spatial issues. The sub-field of spatial econometrics is the fruit of these efforts, and it has grown rapidly since its introduction in the late 1980s.

Since the publishing of Luc Anselin's seminal monograph, *Spatial Econometrics: Methods and Models* in 1988, spatial econometric methods have been widely applied in econometric models across the social sciences (Anselin 1988). This toolbox has assumed a particularly important role in the "spatial" fields and sub-fields such as geography, regional science, and urban economics, where researchers have situated panel data and cross sectional datasets into spatial frameworks for regression analyses. They have used these models to engage directly with land use issues, though these articles from this research remain relatively infrequent in the literature. In the Brazilian Amazon region, spatial econometric tools were first applied to studies of deforestation by Walker, Moran, and Anselin (2000). Several recent studies have also applied spatial econometric tools to consider land use change specifically within the Amazon. Aldrich's (2011) work on contentious land use change in the South of Pará and research on land clearings in Uruará, in the State of Pará by Caldas, et al (2007), for example, both featured spatial econometric methods.

Accounting for a spatial effect compensates for two specific technical sources of spatial bias: spatial dependency, which resembles a spatial variety of autocorrelation; and spatial heterogeneity, which is otherwise unaccounted for in standard regression estimations and is considered a source of error. These spatial biases or relationships are akin, in theory, to Tobler's "first law" of geography, where "everything is related to everything else, but near things are more related than distant things (Tobler 1970)." What happens in one location, evidently, is dependent in part on what happens nearby, as no location exists independently of other observations. In spatial econometrics this dependency is formally considered, and broken into two elements, namely spatial dependence and spatial heterogeneity.

Spatial dependency refers to the presence of endogeneity in the dependent variable. This concept provides much of the conceptual underpinnings to spatial interpolation, where values in one location can be estimated as a function of the values in other, nearby locations. Classic examples of spatial dependence include housing values (e.g., where a value for one home depends on the value of the nearby home) and crime statistics. Spatial dependency is accounted for through spatial autoregressive (SAR) models, where each observation is a function of not only of its associated explanatory variables, but also as of observations in nearby locations.

Spatial heterogeneity, the second spatial effect discussed here, refers to heterogeneity in the distribution of relationships, networks, or other otherwise unaccounted effects that influence observed outcomes, but which may not be derived from the observations themselves. The spatial durbin model (SDM) provides a mechanism by which to account for otherwise unobserved spatial heterogeneity by including lagged explanatory variables. Just as with spatial dependence, the unaccounted presence of spatial heterogeneity violates the critical Gauss-Markov assumptions that underlie econometric estimations (Anselin 1988, Lesage and Pace 2009). In this analysis, the otherwise unobserved influence of the indirect effects of land use change are theorized as occurring within the biases endogenous to spatially heterogeneous relationships.

In much of the spatial econometric literature, spatial influence is determined based on contiguity or through other measurements of neighborhood. Most commonly, this is achieved by either defining a neighborhood based on shared borders (a technique often utilized when analyzing polygon units) or through proximity (for point based datasets). As will be discussed in the following section, in this chapter I adopt an innovative consideration of neighborhood typologies, and employ a creative weighting system to more appropriately distribute the indirect effects from points of origin to points of impact. Given the nature of land use organization in the Amazon, which positions deforestation often at some distance from the point origin of the indirect effect, the situation posed a unique conceptual problem. In the next sections this issue will be addressed, after a more precise description of the spatial durbin model and its associated data generating process.

5.2.1. The Spatial Durbin Model

I selected the spatial durbin model (SDM) as the centerpiece of this econometric analysis. The SDM approach serves the issue at hand, given that the model structure allows for the incorporation of broader spatial impacts through the inclusion of a weighted indirect variable (Lesage and Pace 2009). The SDM captures the effects of nearby observations of both the independent and the observed dependent variables in a specific location by weighting their impacts within a spatial weights matrix. For example (using a slightly crude illustration), crime rates might be viewed as not only a function of police protection in the observed location, but also as a function of both crime rates and police protection in nearby locations.

The key to this work resides in the spatial weights matrix, which is based on a measure of contiguity. Drawing from the classic example used by Lesage and Pace (2009), a neighborhood matrix based on the highway block shown in figure 5.1 translates into the contiguity matrix, *C*, shown as equation 5.1, with contiguity dependent on a shared border. Where an observation is contiguous with another observation, it is marked as one; where no contiguity is observed, a zero. To render the contiguity matrix into a row stochastic matrix for further analysis, a scalar is used to normalize the sum of each row to 1. The result is matrix *W*, shown as equation 5.2.

R1 (y_1)	**R2 (y_2)**	**R3 (y_3)**	**R4 (y_4)**	**R5 (y_5)**	**R6 (y_6)**	**R7 (y_7)**

Figure 5.1: Example of spatial distribution of observations

$$C = \begin{array}{c|ccccccc} & R1 & R2 & R3 & R4 & R5 & R6 & R7 \\ R1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ R2 & 1 & 0 & 1 & 0 & 0 & 0 & 0 \\ R3 & 0 & 1 & 0 & 1 & 0 & 0 & 0 \\ R4 & 0 & 0 & 1 & 0 & 1 & 0 & 0 \\ R5 & 0 & 0 & 0 & 1 & 0 & 1 & 0 \\ R6 & 0 & 0 & 0 & 0 & 1 & 0 & 1 \\ R7 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{array} \tag{5.1}$$

$$W = \begin{matrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ \frac{1}{2} & 0 & \frac{1}{2} & 0 & 0 & 0 & 0 \\ 0 & \frac{1}{2} & 0 & \frac{1}{2} & 0 & 0 & 0 \\ 0 & 0 & \frac{1}{2} & 0 & \frac{1}{2} & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{2} & 0 & \frac{1}{2} & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{2} & 0 & \frac{1}{2} \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{matrix} \tag{5.2}$$

The spatial effect is then calculated by multiplying *W* by the weighted observations of y in each contiguous location, which is summarized as equation 5.3:

$$Wy = \begin{pmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ \frac{1}{2} & 0 & \frac{1}{2} & 0 & 0 & 0 & 0 \\ 0 & \frac{1}{2} & 0 & \frac{1}{2} & 0 & 0 & 0 \\ 0 & 0 & \frac{1}{2} & 0 & \frac{1}{2} & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{2} & 0 & \frac{1}{2} & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{2} & 0 & \frac{1}{2} \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{pmatrix} \begin{pmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \\ y_5 \\ y_6 \\ y_7 \end{pmatrix} = \begin{pmatrix} y_2 \\ \frac{(y_1+y_3)}{2} \\ \frac{(y_2+y_4)}{2} \\ \frac{(y_3+y_5)}{2} \\ \frac{(y_4+y_6)}{2} \\ \frac{(y_5+y_7)}{2} \\ y_6 \end{pmatrix} \tag{5.3}$$

Were observations of nearby locations the only explanatory variables considered in a spatial econometric model, then y_i might be viewed as a product alone of spatially lagged observations in neighboring locations, y_j, and an error term, as denoted in the following expression:

$$y_i = \rho \sum_{j=1\ldots,n} W_{ij} y_j + \varepsilon_i \tag{5.4}$$

where $\sum_{j=1\ldots,n} W_{ij} y_j$ represents the spatial lag, ρ is a scalar term and ε is an error term.

The SDM builds on this model by applying the matrix weighting structure not only to y, but also to a suite of explanatory variables. This is shown in its simplest form as equation 5.5 with its associated data generating process (eq. 5.6-5.7).

$$y = a\iota_n + \rho Wy + x_1\beta_1 + x_2\beta_{2+} Wx_1\beta_3 + Wx_2\beta_4 + \varepsilon \tag{5.5}$$

$$y = (I\text{-}\rho W)^{-1} (a\iota_n + x\,\beta_1 + Wx\,\beta_2 + \varepsilon) \tag{5.6}$$

$$\varepsilon \sim N(0, \sigma^2 I_n) \tag{5.7}$$

where y, the dependent variable, is a function of not only the vector of explanatory variables (e.g., x_1, x_1) assumed in standard, non spatial regression models, but of observations of both y and x in neighboring or nearby locations. The term α is a constant parameter and ι_n is an associated n x 1 vector of ones. Rho, a spatial auto-regressive parameter used to capture the spatial autocorrelation present in the dependent variable, and β_1 through β_4, are the coefficients to be estimated. The coefficients β_3 and β_4 capture the spatially lagged effects from the explanatory variables. Within the data generating process $N(0, \sigma^2 I_n)$ refers to a zero mean disturbance process with a constant variance, σ^2, and I_n denotes an identity matrix of n dimensions.

The full model employed for this analysis will be presented in section 5.4, after a brief introduction to the data used in the study and a more detailed description of each of the weights matrices.

5.2.2. The Arima, et al. model of indirect land use change: similarities and differences

I have theorized that indirect effects disseminate broadly over a spatial landscape. Traditional neighborhood weighting strategies, which privilege proximity, would place the strongest effect on forest cover immediately at the margins of the agricultural frontier, rather than extending it fully to the forest frontier. This is in fundamental odds with the conceptual model described in Chapter IV, where the deforestation frontier occurs at a point that may be well beyond that of the agricultural frontier. To properly estimate an indirect effect under these conditions I would need to erect a bridge to link the two (potentially distant) frontiers. Doing so would direct the brunt of the indirect effect from the agricultural frontier to points of potential deforestation. Conceptually, this bridge would link soybean expansion in one location to losses in forest cover occurring in potentially distant locations, but *not necessarily* to those counties in immediate proximity. In this sense, I needed to reset Tobler's law into a context whereby near things are more related to than distant things, but only as nearness pertains to two subsets of analytical units. As will be noted in the following chapter, at the height of the soybean boom both farmers and ranchers from the relatively distant southern states and elsewhere outside of the region relocated to the margins of the Amazon, indicating that the indirect effect is indeed traveling across an extensive landscape. This theoretical and functional issue poses one of the most significant and fundamental challenges to this analysis.

To meet this challenge this work followed the recent spatial model of indirect land use change put forth by Arima, et al. (2011). The Arima, et al. work built its initial (and essential) analytical bridge between points of origin and points of impact by segregating the Amazon into counties classified as either intensive or extensive frontiers (or neither) based on annual differences in soybean area planted and cattle populations. In the Amazon, where soybean production expanded in area at more than 1/10 the expansion of the cattle herd, municipios were classified as parts of the intensive frontier. Where 1/10 of the increase in the cattle herd surpassed the total increase in soybean area, a municipio was classified as an extensive frontier. In cases where the change in both commodities was nil or negative, each frontier was removed from the sample. Naturally, the frontiers for agriculture and soybean production, as well as their respective impacts and effects, thus varied from year to year. To account for these temporal variations the authors reclassified the frontiers on an annual basis. Years of rapid expansion in both cattle herd populations and soybean area (when more counties were classified as frontier counties) featured a larger sample, while in leaner years the samples of frontier counties were relatively small.

In the Arima, et al. model, once the frontiers were partitioned the intensive frontier counties were then linked to each of the extensive counties using an inverse weighted distance decay structure. In effect, they linked each extensive municipio to each intensive municipio, and weighted the transmission strongest by relative distance (with the most proximate intensive counties thus wielding a stronger neighborhood effect than those in more distant regions). They then used the weighting structure to distribute the broader spatial effects associated with soybean production, with the partition placing the effects directly in zones of forest loss. The total weighted effects distributed to each extensive municipio were subsequently summed and included alongside a vector of local variables (such as price and rainfall) and neighborhood effects of nearby changes in cattle production in fixed effect and ordinary least square regression models.

It is important for me to note that in this dissertation research, while I draw heavily from the approach taken by Arima, et al., I diverge in my conceptualization of neighborhoods in several important respects. First, in contrast to Arima, et al., I seek to preserve a (relatively) stable population of frontiers. For forest frontiers, I selected counties based on access and remaining forest cover; and once selected, they remained in the set of forest frontier counties until or unless the level of forest cover dropped below a certain threshold (this will be further described in the next section). For agricultural frontiers, rather than classifying counties based on soybean expansion in a given year, or in the case of dual cattle and soybean expansion, according to the relative magnitude of increase in comparison to another land use, I classified all counties with an increase in soybean production during the time period as agricultural counties.[9] I viewed this stability in the pool of observations as strengthening an area of weakness in the Arima, et al. model. Rather than selecting only counties with either soybean expansion or growth in the cattle herd and linking them, in effect "cherry picking" the counties of interest by weeding out counties which have not exhibited forest loss; in this model I maintain a more consistent frontier comprising both areas of active and inactive change in forest cover.

This leads directly to another critical point of departure from the Arima, et al. model. Given that many Amazon counties in Brazil experienced both deforestation *and* incurred growth in soybean production at some point over the past decade, and that all soybean expansion was to

[9] Where no increase in soy production was recorded, the weighted effect emanating from these "inactive" counties remained zero. Given the focus on positive increases, only increases in the area of soybean production were considered, i.e., no indirect retraction effect was included.

be included in the analysis, I created a dataset where some municipios could be included in both frontier sets. I saw this approach as more fully capturing the indirect effects of soybean production. For comparison, however, I created two frontier subsets, namely to feature both fully partitioned and non-partitioned frontiers. Once I completed the definition of the frontiers I could then linked each municipio to its respective neighborhood through an inverse distance approach similar to that used by Arima, et al.

I must also mention that this research differs considerably in its construction of its weighting system. Rather than weighing the broader spatial effects according to proximity and Euclidean distance (as was done by Arima, et al.), I constructed weights based on travel costs within a transportation network. I consider the use of travel costs as a measure of connectivity is considered here to be an improvement over standard distance based measures of proximity. This approach also avoids the modifiable areal unit problem, or where neighborhoods of larger municipios outweigh comparatively modest size municipios. Though appearing only infrequently in spatial econometric models (likely owing to the difficulty of calculating large matrices of travel costs), research suggests that the use of travel costs rather than geographic distance provides a more accurate representation of the heterogeneous networks and resource flows being modeled (Lesage and Polasek 2008). I describe this weighting structure in greater detail, along with the data used in the analysis, in the following sections.

5.3. Model Inputs: Data and Weights matrices

5.3.1. Time. This research is based on panel data compiled between 2002 and 2010, an interval that includes both portions of the soybean boom of the early decade (2001-2004), the end of the soybean boom and the slight contraction of the sector 2005-2007, and the most recent resurgence in cropland of 2009-2010. The period was limited, in part, by the availability of data for land prices, which were not available prior to 2002.

5.3.2. Space and Scale . All variables were modeled at the *municipio* scale. The model draws its sample of municipios from across Brazil. It must be recognized that Brazilian municipios are highly varied in size and tend to be larger in more recently settled regions, nowhere more so than in the Amazon.[10] As was discussed in the previous section, the diversity in size of the municipios posed several challenges in to the weighting scheme employed in the analysis.

In addition to their variation in size, Brazilian municipios are not necessarily temporally static entities. Since 1990, more than 1,100 new municipios have been created in Brazil, many of these in the Amazon. As recently as 2001 fifty-three new municipios were "emancipated," thirteen of which were in Mato Grosso. Since 2005, an additional four municipios were created (including two in Mato Grosso: Ipiranga do Norte and Itanhanga, both emancipated from Tapurah). Given the need for spatially static units of analysis for the panel data used in these models, it was essential to limit temporal changes in the base units used in the analysis. To maintain the spatial consistency of the municipal units for the duration of the model's time frame

[10] Brazil's largest municipio, Altamira, Pará, for example, is particularly notable for its size. At more than 161,446 square kilometers , this single municipio is only slightly smaller than the State of California. The larger Amazon municipios stand in sharp contrast to the smaller municipios found in Brazil's coastal states, most which are less than 500km^2 in size.

data the original (e.g., 2002) municipal units were used. This required consolidating data for Tapurah, Ipiranga do Norte, and Itanhanga and limiting the potential time horizon. This approach of consolidating statistics for fragmented municipios has been commonly employed as a means by which to develop the constant set of municipal level units appropriate to panel analyses or other time and space dependent statistical models developed for the Amazon (Barona et al. 2010, Andersen et al. 2002, Arima et al. 2011).

The greatest advantage to modeling at the municipal scale is the availability of data. The municipio unit is widely used as the standard unit for public data collection and analysis, particularly for socio-economic indicators and agricultural and ranching data. There are, however, several shortcomings. As will be discussed in greater detail below, in certain instances municipal level data was not available. In some cases point data was acquired and interpolated across the extent of Brazil; municipal level means, based on these interpolations, were then calculated and included as observations. This means of acquiring data was not considered ideal, however, and it was only used where it was considered to be the best possible option.

5.3.3. Partitioning the frontiers: Forest and Agricultural Municipios

As discussed in the previous sections, one of the principal challenges of this analysis was to analyze the linkages between deforestation in the Amazon to changes in land use occurring not only elsewhere within the Amazon region, but also to changes occurring elsewhere in Brazil. Following Arima, et al., this was accomplished by first selecting two subsets of municipios: frontier municipios [$F = (f{:}f = 1\ldots M$ [Frontier]) and agricultural municipios [A=($a{:}a$ 1… N [Agricultural]).

5.3a Forest Frontiers. For classification as a forest frontier it was essential that a municipio was not only in the Amazon, but also that it was accessible and consisted of excess forest cover, e.g., land which not yet been incorporated into a system of non-extractive commodity production. Such areas are a limited resource, both by nature and by political constraints (such as publicly administered protected areas and property level limitations on clearings, typically either 65% in the cerrado areas or 20% in the Amazon). Given that as forest losses increases the potential area to be cleared is also likely to decrease; rates of deforestation too, may then begin to fall, regardless of the presence of associated explanatory variables. Confresa, a municipio located in northeast Mato Grosso, serves as a useful illustration of this tapering trajectory of deforestation. Rates of deforestation in Confresa were high at the early part of the time period, but declined as the levels of remaining forest cover approached the 65 percent legal limit (table 5.1).

Table 5.1
Rates of Deforestation in Confresa

Year	Area Deforested (square kilometers)	Percent Deforested
2001	267.1	51
2002	347.6	53
2003	129.7	55
2004	120.6	68
2005	143.4	60
2006	69.4	61
2007	66	62
2008	64.9	63
2009	7.6	64
2010	13.3	64

For this analysis it was decided that municipios with less than 30 percent forest cover would be excluded from inclusion as a forest frontier. This benchmark, admittedly arbitrary, would take into account the limited nature of forest areas while acknowledging the constraints of political limitations in what are often extremely remote locations. Whether or not a municipio had already surpassed the thirty percent level of remaining forest cover was determined from the widely used PRODES data, a dataset produced annually by Brazil's National Institute for Space Research. From this dataset, the sum total of area deforested, area not in forest (e.g., cerrado, urban), water area and unobserved areas were summed and divided by total area. This was repeated for each year, in order to omit municipios that had reached and surpassed the 30 percent limit over the course of the study period. Given these restraining parameters, much of the cerrado areas of Mato Grosso and Tocantins, and Maranhão, as well as several of the longer settled municipios of central Rondônia and northern Mato Grosso, were omitted from the analysis.

In addition to possessing reserves of forest cover for clearing, forest municipios were also selected based on road access. Without road access resources were unlikely to flow into a region, just as they are unlikely to flow out. Given that one of the goals of this research was to weight the flow of resources by actual nodes of connectivity, the presence of a roadway connected to Brazil's greater transportation network was essential, both for the design of the weighting structure and for the conceptual framework of the analysis. Much of the Amazon region and, not by coincidence, much of the arc of deforestation, has been integrated into the Brazilian transportation and highway network. However a significant number of municipios, particularly in the northern states where connectivity is via the region's natural waterways, effectively lay disconnected. In these cases, i.e., where road access was *extremely* limited (if not completely absent), municipios were excluded from the subset. This resulted in the omission of the entire States of Roraima and Amapá, most of Amazonas State, and portions of northeastern Pará, including most of the island of Marajó.

Frontiers were calculated based on both a full partition strategy, per the Arima, et al model, and where municipios could be included in both agricultural and forest municipios. In several cases, soybeans expanded in areas classified as forest frontiers (see figure 5.3). In the Legal Amazon soybeans were planted in 292 counties; however, many of these are located in the cerrado region, or have surpassed the seventy percent threshold of deforestation, and thus are not included in the forest frontier set. Nevertheless, sixty-four counties from the set of forest frontiers recorded soybean plantings at some point during the time of analysis. Where soybean production expanded in a municipio classified as a forest frontier municipio, if the area of expansion in soybean production exceeded the area of forest lost it was removed from the forest category and reclassified as a soybean or agricultural frontier. This resulted in a total of 242 (allowing for non-exclusive frontiers) or 202 (fully partitioned frontiers) in 2003, depending on the frontier partitioning (table 5.2). This number declines slightly over the duration of the study period, as in several cases forest levels decreased to below the 30 percent forest cover threshold. By 2010, only 203 and 161 municipios remained in the non-exclusive and fully partitioned forest frontier sets, respectively.

Table 5.2
Number of Forest Frontier Municipios

Year	FF Municipios Non-Exclusive Partition	FF Municipios Full Partition
2003	242	202
2004	239	200
2005	234	185
2006	232	191
2007	232	194
2008	227	183
2009	203	174
2010	202	161
Total Obs.	**1814**	**1490**

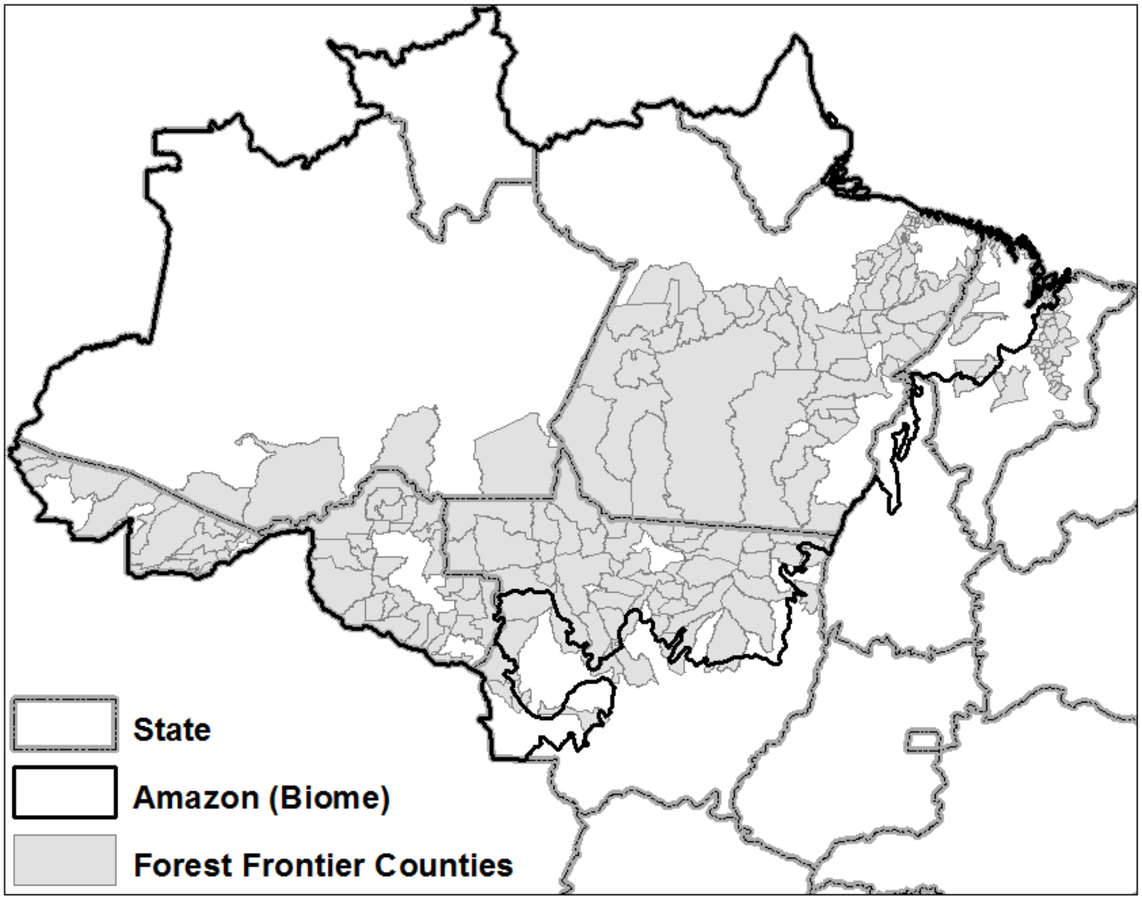

Figure 5.2
Forest Frontiers, 2004

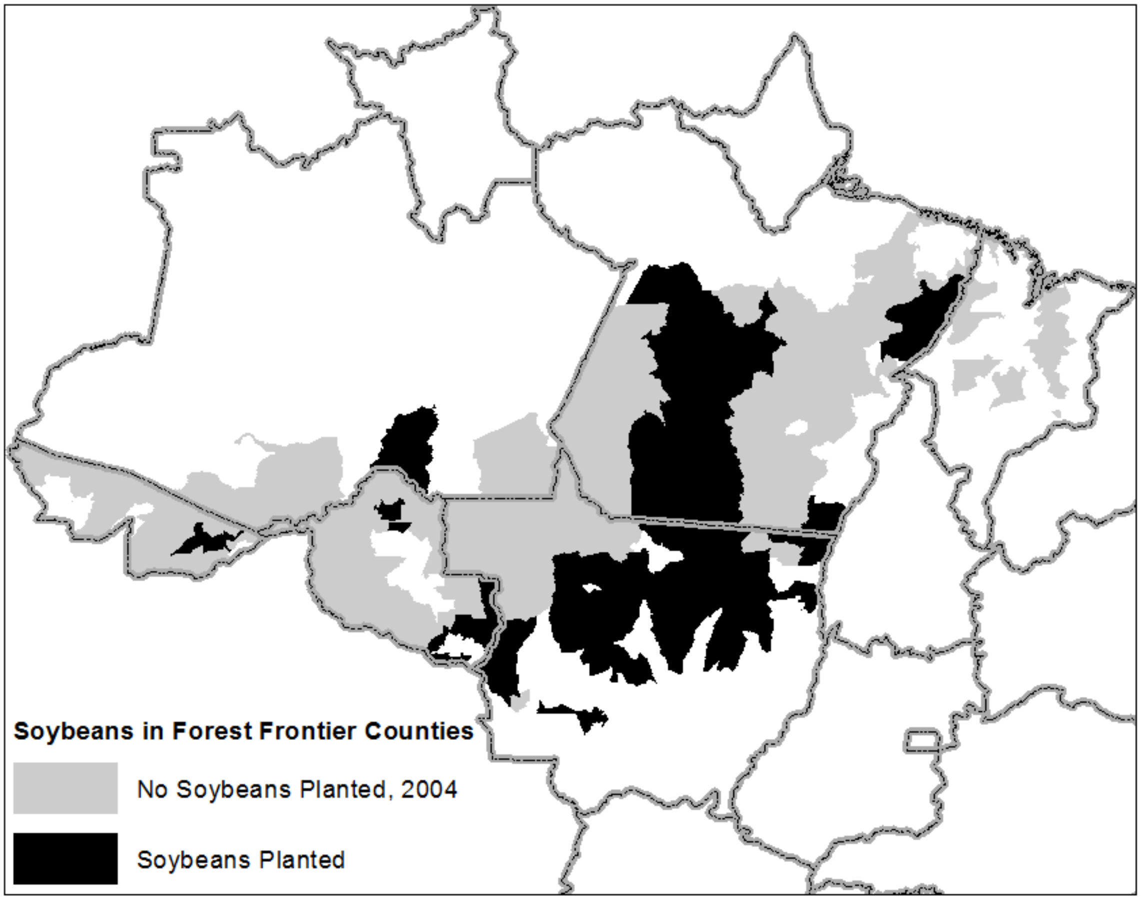

Figure 5.3
Forest Frontiers planted with soybeans in 2004

5.3b. Agricultural Frontiers. In contrast to the forest frontier set, the set of agricultural municipios was calculated through a straightforward examination of growth in soybean areas. Here, any municipio where any soybean expansion occurred between 2002 and 2010 was classified as an agricultural municipio (*n*=2197). The only exception to this relates to municipios also classified as forest frontiers, as indicated above. Also, in contrast to the Arima, et al model, this subset of agricultural municipios was drawn from not only municipios located within the Legal Amazon, but from the entire set of Brazilian municipios (*n*=5807). This set was static, and did not change from year to year (figure 5.2), however production declines (seen on occasion in certain municipios and years) were omitted. Where no change occurs, no effect was calculated, given the nature of the weighting structure (e.g. $W*0 = 0$). Soybean production in isolated areas such as those occurring in northern Brazil in the State of Roraima thus wielded no effect on deforestation, as no land routes existed by which to channel the potential indirect effects to a forest frontier municipio.

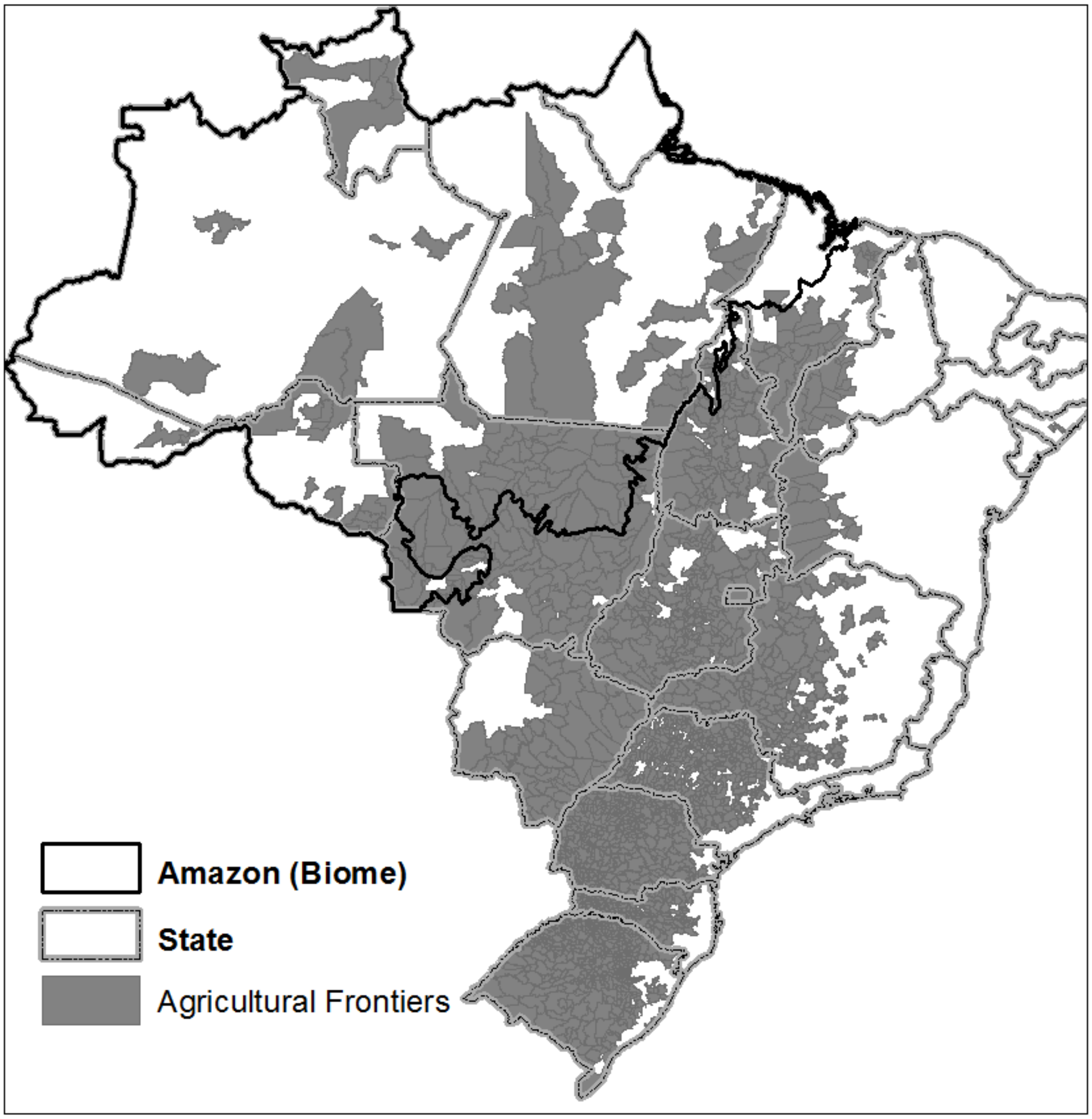

Figure 5.4
Agricultural Frontiers

5.3.4. Spatial weights matrices

In the previous sections it was noted that multiple weighting matrices were used in this analysis. In total, two sets of weights matrices were used, each employing a form of the inverse distance weight structured used by Arima, et al. (2011). The first weights matrix is based on inverse travel costs calculated from a road network. The second weights matrix is a truncated version of the travel cost matrix that limits neighborhood to counties within one hour's drive, or 100 kilometers on paved roads and 50 kilometers by an unpaved road. Each will be described in greater detail in this section.

5.3.4a. Travel Costs. This dissertation sought to distribute spatial effects based on travel costs rather than Euclidean distances. Accomplishing this task, however, posed several important challenges and computationally intensive operations.

First and foremost, to calculate travel costs an entire network needed to be constructed in a GIS system. This was achieved by first acquiring spatially explicit data for Brazil's road network, as well as for the locations each municipal city center. The data acquired was then projected into a distance preserving format, which allowed for the creation of a road network and the calculation of travel times, here used as a proxy for travel costs. To account for variations in road quality, paved roads (the only quality attribute available for the associated road and highway dataset) were assigned an average speed of 100km/hr, or twice that of unpaved roads. These average speeds correspond roughly to my own average travel times driving in the Amazon and its peripheral regions. Once each road segment was assigned an associated speed total travel times could be calculated as a function of segment length and average travel speed. In total, over 55,000 segments were included in this national scale road network (figure 5.5).

I needed to complete several other alterations to the network before the travel cost matrix could be calculated. Many of these alterations were consequential to the peculiarities of the Amazon and the unique conditions of the region's environmental landscape. In Brazil, and particularly in the Amazon, many river crossings are un-bridged and serviced exclusively by ferry transport. Where crossings were un-bridged a barrier emerged in the network, which without correction resulted in extensive rerouting or the disconnection of regions of the Amazon from the remainder of the Brazil. Additionally, a number of inexplicable gaps were present in the GIS road file, some of which may have resulted from human error by the data creator. Many of the gaps were closed manually; others were closed through ArcGIS's snapping tool, set to connect segments separated by less than five km. Several gaps, however, would remain, including those caused by the Amazon River itself, and in several of the larger river crossings breached by the Trans-Amazon highway. As described in the previous sections, it was decided to omit the northern states entirely and to focus exclusively on the southern portions of the basin. Given that the vast majority of deforestation occurs south of the Amazon River, this was not viewed as inhibiting the analysis.

For the network to function properly, I needed to position each of the cities on a road segment in the network. Naturally, most of the cities were already located on the margins of the travel network; however this was not always the case, and in several instances cities were positioned slightly off of the network segments. This was corrected using the automatic snapping tool or through manual relocation. In some cases, however, and particularly in the Amazon, cities have no or minimal road access, are served by regional waterways, or are otherwise disconnected from the larger transportation network. As indicated earlier, such cities were removed from the subset of forest frontiers.

After adjusting the road network, I calculated and arranged a 2688 x 2688 origin-destination (OD) matrix of travel costs using a combination of tools from R and ArcGIS's network analyst. The 2688 x 2688 matrix included all agricultural municipios and each municipio considered to be within the Legal Amazon. I then produced the weights matrix as a function of travel costs, where costs are described as the total hours required for travel from each municipio e to all other municipios, $i \in I$. Here I define D_{ei} as the distances from municipios e to $i \in I$, or as $D = [d, d_{e2}, d_{e3} \ldots d_{ei}]$ with distances determined by the time of travel between the two locations. Finally, I calculated the travel cost based matrix, W^T, by inverting observations of D_{ei}, so that $W_{ei}^T = \frac{1}{D_{ei}}$, with the largest weights being designated to the most proximate or accessible locations, and the smallest weights to the most distant municipios. Municipios that were "off the (transportation) grid" were assigned a connectivity of zero, effectively removing them from further analysis.

Per this weighting structure, soybean expansions taking place farther south, for example in the southernmost State of Rio Grande do Sul, have approximately 1/30th the impact on deforestation in a frontier municipio in the Amazon than soybean expansion in a neighboring municipio would have. Soybean expansion in southern Mato Grosso or Goias, ten hours travel away, would wield an effect on deforestation in northern Mato Grosso of approximately 1/10th of soybean expansion taking place within an hour of driving time or within that specific municipio.

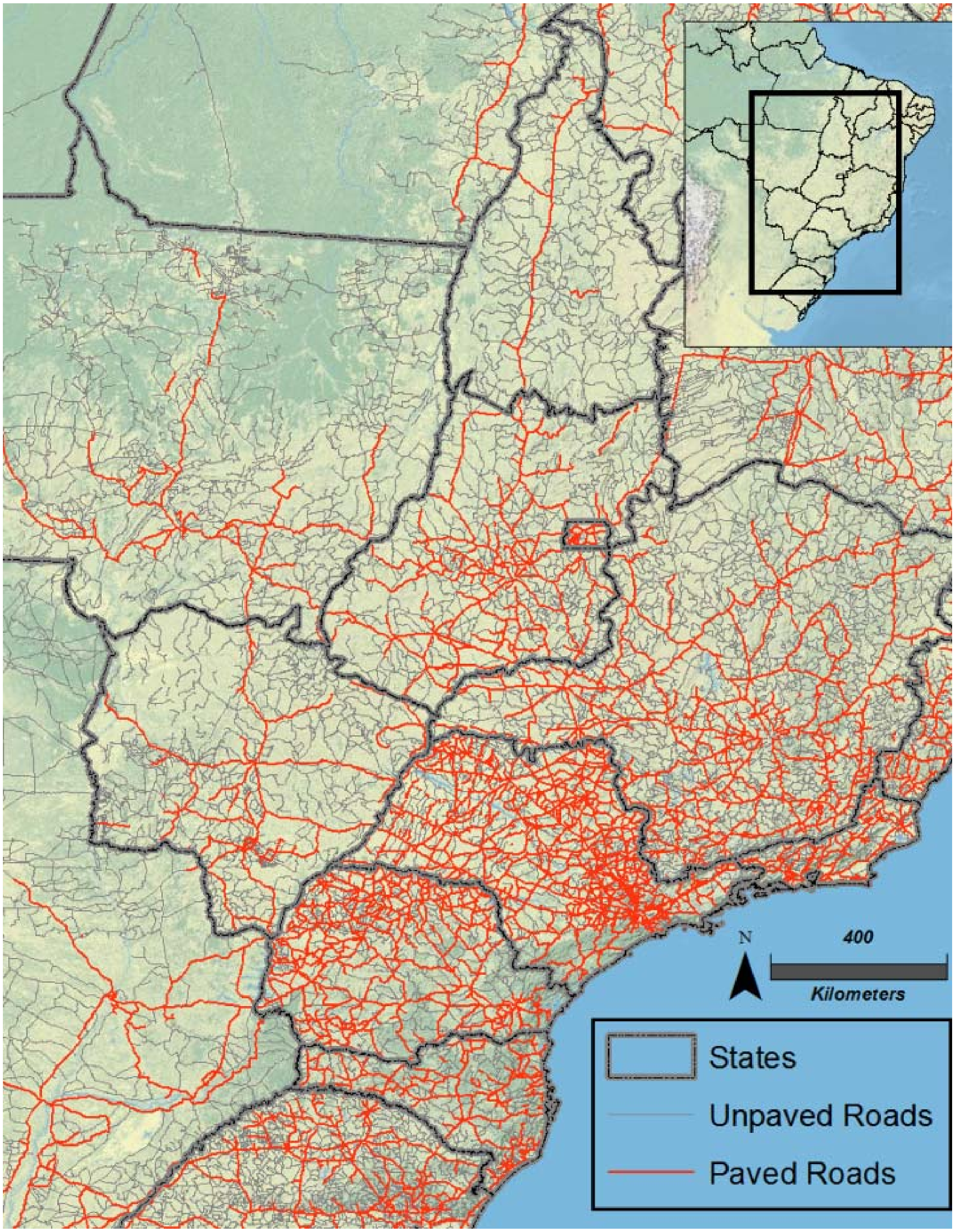

Figure 5.5

Map of paved and unpaved roads in an area of Brazil.

5.3.4b. Travel Costs (truncated I also modified the travel cost matrix to capture the effects of nearby and recent changes in forest cover and cattle production. Here, the intent was not to capture the full range of broader effects of distant deforestation or cattle expansion, but rather the spillover effects more commonly associated with spatial econometric analysis. To accomplish this, rather than fix the number of neighbors or base the effect on municipal contiguity, the travel matrix was simply truncated to include only those municipios located with two hours travel time. The result was matrix W^N, or where changes in cattle populations and deforestation in only neighboring counties were included. This was accomplished by limiting W^T to only where municipios carried a spatial weight of greater than 0.5, or where $d_{ei} < 2$. Where $W_{ei}^T < 0.5$, weights were set to 0. Thus only those municipios that were located within two hrs driving time (200km along fully paved roads or 100km along only non-paved roads) carried a weighted impact. Several municipios that are isolated, or which lay beyond two hours driving time of any other municipal center (such as Novo Progresso) thus contain no neighbors; their "neighborhood" then consists only in changes occurring within their municipio. I included both the cattle and deforestation variables with temporal lags.

5.4. Model Variables: Data and Data Sources

The models tested in this analysis consider a limited number of explanatory variables as determinants of forest loss. Given that the inclusion of the fixed effects parameter controls for diversity in the units of observation, and that the time variables account for temporal changes impacting the region equally, each variable needed to be diverse across both space and time. Deforestation is employed as the dependent variable in each of the models. The set of explanatory variables then consists of: (a) cattle populations; (b) nearby and recent deforestation,

(c) values for pasture, and (d) the indirect effects derived from potentially distant changes in the extent of soybean production. In this section the reasons for including each variable are considered, as well as the data sources and any data manipulation or transformations.

5.4.1. The Dependent Variable: Amazon Deforestation

This chapter, per the first objective of this project, seeks to provide an evaluation and estimation of the linkage between deforestation in the Amazon and previously unseen driving factors, including the indirect impacts of soybean expansion. I therefore model Amazon deforestation, the focus of this work, as the dependent variable. I gathered data deforestation from the municipal level PRODES dataset published by Brazil's National Institute for Space Research (INPE) (2011). The PRODES dataset is derived from 30m resolution LANDSAT images of the Amazon captured at the close of each dry season (Câmara, Valeriano and Soares 2006). Each year, as part of the PRODES project, INPE classifies the entire Amazon as non-forest, forest, water, undetected, or deforested; the latter of which is a permanent classification for the ensuing years, to avoid double counting of forest loss. In addition to providing high resolution land cover maps of year to year deforestation, the PRODES data is also aggregated by municipality and published in annual, municipal level statistics. I downloaded the municipal scale for this analysis dataset directly from INPE.

As described at the outset of this research, deforestation in the Amazon has varied both temporally and spatially during the past decade, though the vast majority of deforestation in the basin has occurred within the 255 municipio bloc known as the so-called "Arc of Deforestation." The highest brute rates of deforestation were generally found in Pará, where the combination of large municipal areas and proximity to the frontier resulted in large losses. However at various times and places in the Amazon's smaller municipios have emerged as leading deforesters. I account for this variation by including a fixed effects parameter.

5.4.2. Cattle Expansion

Much of the growth in the Brazilian cattle herd over the past decade has occurred in the Amazon region, and it is of no coincidence that during this same period the Amazon has experienced some of its highest rates of forest loss. Indeed, linkages between cattle production and deforestation have been prolific in the literature on land use change in the Amazon. In the present models cattle production is included as a time-lagged neighborhood variable. The spatial and temporal lags control for endogeneity. I also consider this approach to be a better fit to the conceptual process being modeled (as forest loss is predicted by *nearby* cattle rather than cattle in a specific location). The growth in cattle in nearby regions results in increasing returns to scale for producers, or an increase in potential rents and new demand for cleared land.

Data on cattle populations was acquired through the Brazilian Institute of Geography and Statistics (IBGE) municipal level statistical database (IBGE 2011b). I attempted to calculate pasture area by estimating stocking densities across Brazil from the 1995 and 2006 agricultural censuses, annualizing the results, and extrapolating pasture areas based on cattle populations. Unfortunately, the data available for pasture areas was clearly unreliable in areas of the Amazon, and nowhere more so than in the frontier areas critical to this analysis.[11] Given that these areas were of principal interest to this study, and that the annualizing of census data would already constitute a degradation of the dataset, I decided to use only the raw data on cattle populations.

[11] Cattle owners in frontier areas of the Amazon may be underreporting their total areas cleared to avoid potential legal issues. In any case, based on the calculated pasture densities, frontier areas such as Novo Progresso were shown as being among the most densely stocked in the nation, which is contrary to the actual case in question.

From the statistics on annual cattle populations annual herd differences were compiled at the municipal level. The resulting [n= 2*688*] vector of differences was then weighted according to the neighborhood weights matrix (based on the truncated travel cost matrix), W^N. This resulted in a weighted vector that was included as an explanatory variable.

5.4.3. Soybeans and the indirect effect

The principal interest of this chapter, and of the dissertation at large, lay in estimating the indirect effects associated with the expansion of soybean production. Soybean production area is thus included as an explanatory variable, albeit one weighted strategically to distribute its effects broadly across Brazil and the Amazon landscape. Annual data on areas planted with soybeans was first acquired from IBGE (IBGE 2011a). Just as with data on cattle populations, annual differences in planted areas were calculated from the dataset and weighted to capture the spatial impacts. The travel time matrix was multiplied by the vector of differentials in annual area of soybeans planted to produce the weighted non-local, soybean effect.

5.4.4. Land Prices

The theoretical positioning of this dissertation is that changes in land prices act as an incentive for the relocation of human and financial capital from one region to another. This positioning is by no means exclusive to this dissertation, as suggestions that changing land prices have provided incentives for land use change has been put forth increasingly in recent years (Nepstad et al. 2006, Vera-Diaz et al. 2008, Richards 2012). Per this argument, land prices rise with the demand for land, and new lands are brought into production. As prices for land fall, so too does the interest in investing in land, and thus so too do levels of deforestation, a form of investment (Campari 2005, Alston et al. 1999, Almeida and Campari 1995).

Land prices are also a proxy variable for land rents. Land values represent a stream of net expected benefits associated with a land parcel. By including land values rather than land rents calculated from the current stream of benefits, land speculation is also accounted for, as well as any other location specific changes, such as a new road, slaughterhouse, or agricultural facility that might encourage new production. Land price data has rarely, if ever been used in a regional scale econometric analysis of deforestation in the Amazon, largely owing to the lack of the data's availability, though in recent years data from the *Fundação Getulio Vargas* (FGV) has been employed as an indicator of land rents (Chomitz and Thomas 2003). Unfortunately, the FGV index of land prices neither discriminates on the basis on land quality nor according to land covers, both of which are viewed here as critical differentiable factors of production. The emergence of a detailed, annual database of land prices published by the Instituto Economica FNP (FNP), an agricultural consulting firm specializing in agro-economic indicators, however, presents a favorable alternative, though this data poses its own limitations.

The FNP data is both expensive and only distributed in print form. Issues also exist in relation to the scale of the data, which is not distributed in the municipal level format that is common to the publically produced data published by IBGE. FNP publishes data on land prices for multiple land qualities at regional scales, based on units of aggregated municipios, many of which may not correspond to the political units used in public censuses and databases. For example, rather than processing and presenting data at the municipio scale, FNP consolidates the 5,561 Brazilian municipios into 133 regions. For each region, multiple prices, each based on indices of properties reported as purchased or sold, are indicated for several municipios and land qualities in each of these regions; in total, approximately 1,200 prices are listed for each year (amounting to more than 10,000 observations over the duration of the study period). Owing in part to the issue of reconciling the incongruent spatial units, FNP prices have been rarely employed in research on land use change in the Amazon, though recent instances do exist (Bowman et al. 2012, Richards 2012).

Reconciling the FNP data with the data used in this study would require rendering the FNP database congruent to the municipal scale data available for the other variables. To accomplish this task, I needed to first enter each observation from the FNP *Agrianual* (2002-2011) yearbooks into an electronic spreadsheet. I then had to standardize the listed land qualities, which vary according to the region or municipio in question, to enable their comparison (table 5.3). The lands listed in the FNP database range from low to high qualities, or from hard to reach forest areas to mechanized cropland planted with sugarcane crops or other perennials. The qualities listed for each region varied with the specific attributes of each location (e.g., cerrado, natural pastures, orchards, and sertão are present only where appropriate, while orange plantations may be listed in regions in São Paulo).

Table 5.3 Sample of Land Quality Classifications

Category	Classification
Unusable land Dense cerrado Unusable Cerrado Forest (difficult access) Native pastures Varzea	Low Quality
Natural land Covers Forest Sertão/Caatinga Cerrado	Unused
Pasture Formed pasture Pasture (high/low support)	Extensive
Agricultural land High support For grain production Mechanized Mechanizable Sugarcane Irrigated	Intensive
High intensity agricultural land Fruit production Coffee	Highest Intensity

For this analysis I standardized the FNP database according the scale of the intensity of investment and land use associated with each parcel price (table 5.3). Lands that were either unusable for commodity production or already in high intensity uses were omitted from further analysis. Of the remainder, each observation was sorted into one of three categories: natural land covers [N], pastures [P], and mechanized(able) croplands [L]. Where multiple land qualities were included for one of the three land covers classifications for the same location (e.g. cropland and sugarcane or degraded and high support pastures, were included in the same region), the price for the higher quality land was included and the lower price was dropped from the dataset. The only exception to this rule was where prices were listed for both soybean and sugarcane croplands; in these cases the price of agricultural land for soybean production was used rather than the more intensive sugarcane-planted cropland. The resulting subsets included annual observations of 354 pasture prices, 179 cropland prices and 183 prices for natural land covers. Within the regions each of the prices listed was (usually) linked to a specific municipio, or small group of specific municipios, which were situated spatially by joining them to a GIS file of municipal point locations.

The next challenge was to then interpolate the information across Brazil. I accomplished this using inverse distance weighting (IDW)[12] tools included in the Spatial Analyst Toolbox from ESRI's ArcGIS software. I calculated means for each municipio, which I could then use for further analysis (figures A.1-A.3, Appendix I); this resulted in the final explanatory variable, P^P, or the price of pasture.

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[12] IDW Interpolation was conducted based on the four nearest points using the power of 3 (closer points are awarded more influence than farther points). Maximum range of influence was set at 2 decimal degrees, or approximately 200km.

5.4.5. The Model

With the weights matrices and the explanatory variables forming this panel set now defined, the general form of the SDM models can now be stated as:

$$D_{i,t}^{f} = c_i + y_t + \psi W_i^N D_{i,t-1} + \varphi W_i^T S_{i,t-1}^{a,x} + \Phi W_i^N C_{i,t-1} + \beta P_{t-1}^{P} + \varepsilon \tag{5.13}$$

The SDM shown as eq. 5.13 is a two way fixed effects model where $D_{i,t}^{f}$, the dependent variable, is deforestation in municipio *i* from subset *f* (*f=forest frontier set*) in year *t*. The notation *c* is the so-called fixed effects estimator, which acts as a control for static differentials in factors such as municipio size, biophysical conditions such as rainfall or soil type, and market access, conditions which generally do not change from year to year within the period of analysis (Wooldridge 2009).[13] Time specific effects, shown here as γ_t, are also included as a control parameter to capture year by year variations that affect the observations uniformly, such as market shifts of changing policies. The remaining variables, as explained in the previous section, include $W_i^N D_{i,t-1}$, or deforestation in nearby municipios (within two hours driving times) during the previous year, were weighted according to the neighborhood matrix. I then weighted the spatial impacts associated with soybean production by inverse travel costs, resulting in $W_i^T S_{i,t-1}$. The expansion of cattle herds are included as $W_i^N C_{i,t-1}$, or the growth in cattle herds in nearby municipios during the previous year. A final variable, P_{t-1}^{P}, is

[13] While road access and policies/policy enforcement certainly have changed during this period of analysis, no data is available by which to estimate these changes on an annual basis.

the appreciation of pasture area during the previous year. Summary statistics for each of the variables are included in tables 5.4-5.

One year lagged variables were included for the weighted variables for neighborhood cattle expansion and deforestation. Given the time required to put new land into agricultural production and for a rancher to open new lands in the Amazon, the indirect effect associated with soybean expansion is considered to have a built-in lag period, e.g. the relocation process and the new land clearings may come in the year prior to the soybean expansion due to temporal constraints on land preparation. The time needed for the displacement effect to manifest itself, however, is unclear, and the process may require more than a single year lag. All variables were tested both logged and unlogged (where logged, to avoid attrition in the sample, natural logarithms were calculated as $1 + x$, with x signifying all weighted explanatory variables). The parameters to be estimated are the coefficients ψ, γ, φ, Φ, and β.

I tested the models on two datasets. In the first I included the non-partitioned data, where neighborhoods may overlap, or where the neighborhood of forest frontiers may include municipios simultaneously included in the agricultural frontier. I partitioned the second dataset, following Arima, et al (2011) according to agricultural and forest frontiers. Tests were conducted using each dataset, and using both logged and unlogged variables. As will be discussed later in the chapter, in section 5.6 additional estimations were conducted to test for potential endogeneity and data manipulations.

Table 5.4 *Variable Summaries for Non-Partitioned Forest Counties*						
Variable	**Sign**	**Obs.**	**Mean**	**Std. Dev.**	**Min**	**Max**
Deforestation (square kilometers)	D_i	1811	53	112	0	1405
Land Price ($Rs/Ha of Pasture)	P_t^P	1811	1306	656	107	3562
Inv. Transport Costs (Hours) * Change in Soybean Planted Area (Ha)	$W_i^T S_i$	1811	38	28	5.63	206
Total Local Cattle Change (Head)	$W_i^N C_i$	1811	18	49	-176	487
Total Local Deforestation (square kilometers)	$W_i^N D_i$	1811	258	314	0	3243

Table 5.5 *Variable Summaries for Partitioned Forest Counties*						
Variable	**Sign**	**Obs.**	**Mean**	**Std. Dev.**	**Min**	**Max**
Deforestation (square kilometers)	D_i	1400	62	121	0	1405
Land Price ($Rs/Ha of Pasture)	P_t^P	1490	1309	655	111	3509
Inv. Transport Costs (Hours) * Change in Soybean Planted Area (Ha)	$W_i^T S_i$	1490	36	25	5.8	204
Total Local Cattle Change (Head)	$W_i^N C_i$	1490	19	53	-176	487
Total Local Deforestation (square kilometers)	$W_i^N D_i$	1490	283	329	0	3243

5.5. Model Results

The results of the model, presented in full in table 5.6, indicate that the expansion of soybean production in the settled, consolidated agricultural regions wields a significant and positive effect on forest loss in the Amazon. The estimated elasticities of deforestation with respect to soybean expansion for the logged models are 2.29 for the non-partitioned frontier set and 1.01 for the fully partitioned frontier set. These statistics indicate that for every one percent increase in the weighted soybean effect, an increase in deforestation of between 1.01 and 2.29 occurs as a response.

The larger coefficients associated with the non-exclusive frontiers are artifacts of the non-partitioned frontier structure. The non-partitioned dataset considers not only the expansion of soybean production across broader Brazil, but also production expansions occurring within the forest frontier municipios themselves. Owing to the weighting structure, which emphasizes the effect of near over distant expansions, the inclusion of local soybean expansion in the weighted effect is more likely to impact forest cover. Consequently, a one percent increase in soybean production across all of the soybean areas, including within the forest frontier regions themselves, is likely to wield a larger impact than an increase in only those areas outside of the frontier municipios. The results are slightly different for the unlogged models, however; here the coefficients for the weighted soybean variable were 1.06 (non-partitioned) and 1.72 (partitioned). In each of the weighted models the weighted, indirect soybean effect was positive and significant at the 0.01 level. In three of the four models I estimated the indirect soybean effect was significant at the 0.001 level.

Extrapolating the impacts of soybean production and producing a firm estimation of the impacts associated with deforestation from the estimated results is, unfortunately, complicated by the weights matrices used in their calculations. Given the structure of the data weighting process, the effect of a soybean expansion is very much related to the distance between that location and its potential impact. A reduction in growth in soybean production taking place is southern Brazil, in comparison to new production taking place in Mato Grosso, will have a smaller impact on reducing deforestation. Conversely, a larger reduction in soybean production in Mato Grosso will carry a larger effect. As a consequence, any estimation of forest savings associated with a reduction in soybean production will be contingent on not only the size of the reduction, but also where it is that that reduction took place. However, deforestation reduction can be estimated based on a 10% across the board reduction in soybean production across all of Brazil.

Based on the estimated coefficients for the indirect or weighted soybean effect, hypothetical deforestation reductions resulting from a 10% reduction in the growth of soybean production during the study period (2003-2010) ranged from a savings of 13,434 to 30,460 square kilometers. Relative to deforestation taking place across the Amazon, this amounts to between 10% and 23% of forest loss in the Amazon occurring between 2003 and 2010. These analytical results provide a clear confirmation of the so-called indirect effect. The estimations are similar to (if slightly more than) other recent modeling efforts, including those of Arima, et al (2011), who estimated deforestation reductions associated with a 10% decline in soybean production as ranging between 5,000 (with no time lag) to 26,000 square kilometers with a one year time lag for soybeans. These estimations also support a growing body of literature recognizing the potentially broader spatial impacts associated with land use change.

Table 5.6 Model Results				
	Model 1a	**Model 1b**	**Model 2a**	**Model 2b**
Model Description	All Logs Non-exclusive Frontiers	All Logs Exclusive Frontiers	No Logs Non-exclusive Frontiers	No Logs Exclusive Frontiers
Nobs	1336	1039	1727	1345
F	92.07	68.55	28.52	23.62
Prb> F	0.00	0.00	0.00	0.00
R2	0.89	0.88	0.76	0.78
Adj R2	0.86	0.84	0.72	0.73
	Estimated Coefficients (standard errors)	Estimated Coefficients (standard errors)	Estimated Coefficients (standard errors)	Estimated Coefficients (standard errors)
$W_i^N D_{i,t-1}$	0.33 (0.04)***	0.34 (0.06)***	0.032 (0.01)**	0.015 (0.02)
$W_i^T S_{i,t}$	**2.29 (0.32)*** **	**1.01 (0.50)***	**1.06 (0.19)*** **	**1.72 (0.35)*** **
$W_i^N C_{i,t-1}$	0.07 (0.03)*	0.10 (0.03)*	-0.07 (0.11)	-0.10 (0.05)
P_{t-1}^P	0.19 (0.11)	0.14 (0.11)	-0.01 (0.01)	-0.12 (0.01)
2003	0.94 (0.14)***	-0.78 (0.70)	7.84 (12.29)	30.01 (10.86)***
2004	(Dropped)	-1.16 (0.86)	-24.07 (11.59)*	(Dropped)
2005	0.60 (0.12)***	-1.02 (0.74)	-13.57 (8.85)	14.67 (9.60)
2006	2.76 (0.49)***	-0.45 (0.17)***	-10.52 (3.42)**	26.64 (16.78)
2007	3.75 (0.61) ***	(Dropped)	(Dropped)	33.95 (17.66)
2008	1.30 (0.27)***	-1.07 (0.54)*	-24.55 (5.46)***	0.14 (12.92)
2009	1.50 (0.38)**	-1.30 (0.38)***	-34.7 (5.55)***	-5.34 (16.73)
2010	0.41 (0.20)*	-1.54 (0.65)*	-50.58 (8.04)***	-32.16 (14.05)*
Cons	-9.72 (1.44)	-2.37 (1.30)	36.47 (9.07)**	-9.94 (21.12)
*** Sig @ 001	** Sig @ .01	*Sig @ .05		

Table 5.7

Estimated Reduction in Deforestation (square kilometers)

Year	10% Change in Soy Area in Agricultural Frontiers	**Non-Exclusive** φ =2.29	**Partitioned** φ =1.01
2003	2,341	5,361	2,364
2004	3,210	7,350	3,242
2005	2,220	5,083	2,242
2006	585	1,339	591
2007	529	1,212	535
2008	1,329	3,044	1,342
2009	1,181	2,705	1,193
2010	1,907	4,366	1,926
Total	**13,301**	**30,460**	**13,434**
	Deforestation in AML	Percent Reduction in Deforestation with 10% Reduction in Soybean Expansion	
2003	30,382	17.65%	7.78%
2004	27,136	27.09%	11.95%
2005	23,902	21.27%	9.38%
2006	10,912	12.27%	5.41%
2007	11,493	10.55%	4.65%
2008	13,344	22.81%	10.06%
2009	6,135	44.09%	19.45%
2010	6,350	68.75%	30.32%
Total	**129,654**	**23.49%**	**10.36%**

5.6. Additional Specifications and Model Weaknesses

The results presented in the previous sections are contingent upon a series of data manipulations and weighting structures contained within the principal models. Notably, this included several areas of potential distortion, including (a) a weighting structure and the inclusion of the weighted spatial variables, (b) the addition of one prior to transforming the unlogged variables into logged variables for inclusion in the log-log model, and (c) potential endogeneity in the weighted soybean variable. I briefly discuss each of these issues in this section; and in response several supplementary models are developed, the results of which are included in tables 5.8-5.10.

5.6.1. Comparison with the non-spatial model

The decision to include a spatial variable is often contingent upon indicators suggestive of spatial autocorrelation in the error term. Common tests for the presence of a spatial effect include the Moran's I test and the Breusch-Godfrey serial correlation LM error test. Of these, the former examines spatially explicit data for correlation in observations in nearby or neighboring locations, while the LM error test examines serial dependence in the error term. Neither test was conducted on the dataset used here, an omission that stems, in part, from the difficulties of incorporating a weights matrix based on transportation costs and travel times (as was created for this analysis) rather than geometric or geographic proximity. More pertinent, however, was that this dissertation focused on capturing effects that were not emanating from neighborhood locations but rather from potentially very distant units of observation. Thus the role of soybean production in the present model is not as a local or even neighborhood variable in the forest frontiers, but rather as the weighted aggregate of changes occurring largely in the transitional Amazon regions at the southern and western ends of the basin and in the nation's south. The LM error tests and the Moran's I were not designed to test for such distant impacts on land use, and thus were not conducted as part of this analysis.

Nevertheless, the importance of including the weighted variables for not only soybeans, but also for the time-lagged area variables of changes in cattle population and deforestation, was tested by comparing the results of the original log-log models with regressions where the spatial variables were omitted. The spatial and non-spatial models were compared based on AIC criteria and on their relative R^2 values. Notably, in the non spatial model using the non-partitioned dataset the AIC increased from 2,539 (spatial variables included) to 3,504 (Table 5.9). Similar results were seen in the associated AICs for the partitioned dataset, where the increase was only slightly less, from 1,809 to 2,526. These results were also reflected in the models' respective R^2s, which dropped from 0.89 (non-partitioned) and 0.88 (partitioned) to 0.86 (in both models). The results indicate that the inclusion of the spatial variables significantly improve the model of forest loss.

5.6.2. Logged variables

As indicated in section 5.4, in models 1a and 1b, prior to taking the natural logarithm of the raw data the value one was added to each explanatory variable. This step was taken with the intention of maximizing the number of observations; as without this manipulation several municipios not recording deforestation in a given year (e.g., where deforestation = 0) would be removed from the log-log models. In the non-partitioned (non-exclusive) 39 observations in the log-log model would be lost, or n would fall from 1336 to 1297. In the partitioned model the drop was slightly less, from 1039 to 1008. It is important, however, to ensure that these transformations have not greatly distorted the results. To maintain clarity, a set of secondary, log-log models were rerun without the addition manipulation.

Estimating the models using the non- manipulated (without adding 1 to the original observation) logged variables indicated little or no difference from models 1a and 1b. In each case the estimated coefficients and their associated standard errors remained within 0.05 of the estimates from the original models. Comparing the overall results of the non-modified log models with the original models were inconclusive, with the R^2 and AIC being nearly equal in the non-partitioned frontiers, but significantly different in the partitioned dataset. For the latter, the AIC score increased from 1809 to 2216 while the R^2 decreased from 0.88 to 0.86. . The full results from these models are included in table 5.8 and 5.9 as models 1a.2 and 1b.2.

Table 5.8. Comparative Models (I)			
	Model 1a	**Model 1a.1 No spatial vars**	**Model 1a.2 Non-modified logs**
All vars logged	Non- Partitioned Frontiers	Non- Partitioned Frontiers NoSpatial	Non- Partitioned Frontiers Non-modified logs
Nobs	1336	1727	1297
F	92.07	40.55	94.67
Prb> F	0.00	0.00	0.00
R2	0.89	0.86	0.89
Adj R2	0.86	0.84	0.86
$W_i^N D_{i,t-1}$	0.33 (0.04)***		0.35 (0.04)***
$W_i^T S_{i,t}$	**2.29 (0.32)*** **		**2.29 (0.33)*** **
$W_i^T S_{i,t-1}$			
$W_i^T S_{i,t-2}$			
$W_i^N C_{i,t-1}$	0.07 (0.03)*		0.08 (0.02)***
P_{t-1}^P	0.19 (0.11)	0.20 (0.10)	0.15(0.11)
2003	0.94 (0.14)***	1.44 (0.16)***	0.91 (0.15)***
2004	(Dropped)	1.32 (0.12)***	(Dropped)
2005	0.60 (0.12)***	1.15 (0.10)***	0.60 (0.12)***
2006	2.76 (0.49)***	0.57 (0.08)***	2.87 (0.52)***
2007	3.75 (0.61) ***	0.48 (0.08)***	3.94 (0.65)***
2008	1.30 (0.27)***	0.71 (0.07)***	1.32 (0.27)***
2009	1.50 (0.38)**	0.2 (0.07)	1.57 (0.39)***
2010	0.41 (0.20)*	(Dropped)	0.47 (0.21)*
Cons	-9.72 (1.44)	0.87 (0.90)	-28.24 (3.97)***
AIC	**2,539**	**3,504**	**2,425**
*** Sig @ 001	** Sig @ .01	*Sig @ .05	
Weighted soybean effect is shown in bold			

Table 5.9 Comparative Models (II)			
	Model 1b	**Model 1b.1 No spatial vars**	**Model 1b.2 Non-modified logs**
All vars logged	Partitioned Frontiers	Partitioned Frontiers No Spatial	Partitioned Frontiers Non-modified logs
Nobs	1039	1345	1008
F	68.55	73.91	60.68
Prb> F	0.00	0.00	0.00
R2	0.88	0.86	0.86
Adj R2	0.84	0.83	0.82
$W_i^N D_{i,t-1}$	0.34 (0.06)***		0.34 (0.08)***
$W_i^T S_{i,t}$	**1.01 (0.50)***		**0.96 (0.61)**
$W_i^T S_{i,t-1}$			
$W_i^T S_{i,t-2}$			
$W_i^N C_{i,t-1}$	0.10 (0.03)*		0.09 (0.04)**
P_{t-1}^P	0.14 (0.11)	0.11 (0.10)	0.12(0.13)
2003	-0.78 (0.70)	1.32 (0.16)***	-0.25 (0.23)
2004	-1.16 (0.86)	1.31 (0.12) ***	(Dropped)
2005	-1.02 (0.74)	1.13 (0.11) ***	0.09(0.16)
2006	-0.45 (0.17)***	0.53 (0.10) ***	0.58 (0.93)
2007	(Dropped)	0.43 (0.10) ***	0.97 (1.13)
2008	-1.07 (0.54)*	0.65 (0.08) ***	-0.07 (0.44)
2009	-1.30 (0.38)***	-0.14 (0.06)	0.36 (0.65)
2010	-1.54 (0.65)*	(dropped)	-0.50 (0.32)
Cons	-2.37 (1.30)	1.62 (0.75)*	-11.50 (7.29)
AIC	**1,809**	**2,526**	**2,216**
*** Sig @ 001	**Sig @ .01	*Sig @ .05	

5.6.3. Potential endogeneity in the soybean effect

This dissertation has been written under the assumption that soybean production is a driver rather than a "follower" of deforestation. Much has been written on deforestation in tropical regions as being perpetuated primarily by timber companies or smallholder farmers (Palm et al. 2005, Labarta, White and Swinton 2008). This work has given rise to the emergence of what some researchers have referred to as the so-called "hollow frontier" thesis. Per this framework, the frontier occupation process begins when timber companies establish new access roads. They are followed in turn by smallholder farmers, who move into the region to claim land, clear the remaining vegetation, and establish their own small farms. Over time, due to unsustainable farming practices land is abandoned, the buying power of ranchers interested in the property proves irresistible to recent occupants, or claimants succumb to the outright force of those seeking to "grab" the land, and smallholder farms are replaced with ranches. Gradually, as pasture productivity declines ranchers seek new lands and move forward toward the frontier, thus allowing another transition, namely one from ranching to commodity agriculture, to take place.

Per this framework, the emergence of commodity agriculture appears to follow in the wake of ranching, or to take advantage of land improvements made by successive and previous waves of labor and capital. From such a perspective, commodity agriculture then might be conceived as endogenous to deforestation at the frontier. This is at odds with the general thesis of this work, where the expansion of agriculture acts not as a follower of deforestation, occupying the less fertile, exploited regions abandoned by ranchers, but rather as a driving force behind the expanding frontier.

To test for a potential reverse causal effect this dissertation examined the weighted soybean effect for endogeneity through a Durbin-Wu-Hausman (DWH) test. The DWH test for endogeneity is suitable for testing for endogeneity in a single explanatory variable. I conducted the DWH test by first regressing the potentially endogenous variable (in this case, the weighted soybean effect) on all of the explanatory variables and the additional instrumental variables (IVs) and then inserting the estimated residuals into the structural equation, along with the potentially endogenous variable. The residuals I estimated from the first equation I then tested for difference from zero, with the null hypothesis being that there is no difference, or that the variable is not endogenous. A high DWH test score and a low associated p value indicates potential inconsistency in one (or both) of the estimators (Wooldridge 2009). Generally, a p-value of less than 0.10 is considered to indicate endogeneity.

In the present case, testing for endogeneity involved constructing an instrumental variable that correlated with changes in the agricultural frontiers but not in the forest municipios. That this instrumental variables would need to emanate from the agricultural municipios themselves made this process somewhat more difficult. Cropland prices, which I had data for and which are correlated to the expansion of soybean production, I felt to be unusable as an IV, as, per the theoretical foundations outlined in Chapter IV, land prices provided an underlying incentive for migrants to relocate to frontier regions. For this analysis then I used changes in rural and urban populations as instrumental variables. I considered that urban populations were more likely to increase with the presence of new soybean production, as the increased economic activity stimulates economic growth and draws new labor into the region. Conversely, I assume that rural populations would be negatively correlated with the expansion of soybean production, with rural, smallholder farmers being displaced by expanding soybean fields or drawn out of the area by increasing opportunities in the urban sector.

As with data on agricultural areas and cattle populations, population data was acquired from IBGE's online SIDRA portal (IBGE 2000, IBGE 2010). Unfortunately, population data was not available on an annual basis, but rather was only available through the national censuses, which the federal government conducted in 2000 and 2010. I then calculated the necessary year by year differences in populations by annualizing the data, or by dividing the sum difference over the ten year time period by ten. Because the soybean effect only emanates from those counties where a positive increase in soybean production occurred, population data was only included where a positive change in soybean production occurred. I then weighted the data through the same mechanism used for soybean production to produce a weighted population effect. Summary statistics for the population variables in both the fully partitioned and non-partitioned models are included in table 5.10.

***Table 5.10. Urban and Rural Population Growth**W_i^T*

	Obs	**Mean**	**Std. Dev.**	**Min**	**Max**
Urban (unpartitioned)	1975	7.45	3.73	0.01	29.17
Rural (unpartitioned)	1975	-0.40	0.32	-2.13	0.65
Urban (partitioned)	1654	7.13	3.31	1.37	27.79
Rural (partitioned)	1654	-0.40	0.30	-1.97	0.65

Following Wooldridge and the methods outline above, the (partitioned and non-partitioned) soybean effects were regressed on the two instrumental variables, rural and urban changes in population (with a one year time lag) and the assumed exogenous variables (the one year lagged neighborhood cattle and deforestation effects and the price of pasture), and the year time dummies in a fixed effects model. Four sets of residuals were estimated, with one corresponding to each of the original models (1a, 1b, 2a, and 2b). The residuals were then inserted into each of the original models and tested for difference from zero. The results are shown in table 5.11. The full results of these models are included in the appendix as tables A.1 and A.2

Table 5.11.
Durbin-Wu-Hausman Tests for Endogeneity

	DWH Test Stat	Probability>F
Model 1a	1.96	0.16
Model 1b	4.64	0.03
Model 2a	0.00	0.98
Model 2b	0.88	0.35

The results of the endogeneity tests indicate no endogeneity in the partitioned models (models 2a and 2b) but potential endogeneity in the non-partitioned models (1a and 1b). This is to some degree to be expected, given the nature of both the instrumental variable and the weighting process. As indicated earlier in this chapter, the partitioned model controls for endogeneity in the soybean variable by effectively erecting a spatial curtain between the two sets of frontiers. However, in the non-partitioned models this partition is no longer present; additionally, it is highly likely that the population variables used as IVs in this analysis are also endogenous to deforestation in the forest frontiers. Nevertheless, it may be concluded from the DWH tests that there is no endogeneity in the partitioned dataset.

5.6.4. Additional Limitations to the Modeling Results

The results presented in this chapter were subjected to several additional limitations that merit recognition and several ambiguities exist in regard to the scale and nature of the data employed. It must be recognized, for example, that the data used to estimate pasture areas was based on raw figures for cattle populations. Data on the spatial extent of pastures, when available, appeared to be inaccurate, particularly in the Amazon region where information on cleared lands may be more difficult to find. Discussions with industry officials confirmed the inaccuracy of the data on pasture areas published in the agricultural censuses, which was felt to have often omitted large ranches and overly focused on smallholder producers. This discrepancy resulted in the vast overestimation of stocking densities, particularly in frontier areas, and rendered extrapolated calculations of pasture area unusable. Calculations of animal density from total pasture areas and cattle populations, for example, suggested that Novo Progresso, a frontier region central to this analysis, contained some of the highest stocking rates in the nation. It is more likely in this case that landowners failed to report the extent of their pastures due to (a) the rapid rate at which new pasture were being cleared and (b) new pastures were cleared illegally, and landowners sought to conceal their creation. Nevertheless, the conceptual model design requires a consideration of pasture areas displaced rather than herds of cattle, which were used in substitute.

Another limitation to the model is derived from its spatial scale. Using municipal level statistics rather than the spatially explicit results of remote sensing data forced the model to be conducted at a broader scale. However, in recent years advancements in remote sensing have enabled the assessment of land use, in addition to state of clearing, which would have allowed for the calculation of not only pasture area, but also of crop intensification. Ideally, this model would have incorporated such spatially fine data rather than the municipal scale data provided through IBGE. This would have not only improved accuracy, but it would have allowed for the explicit consideration of land use transitions, rather than relying on aggregated changes in statistical reports.

Another significant limitation to this analysis is the limitation of the soybean effect to municipios where soybean areas actually declined. Per the classification scheme, I only assigned areas of positive changes in soybean production to the agricultural frontier set. Thus any effect associated with a decline in agricultural production would be rendered neutral. Not capturing the negative effect of a soybean decline on areas of deforestation likely biases the final estimations.

This dissertation also omits timber prices, though; from a theoretical standpoint timber prices would constitute a significant driver of land clearing, assuming that the timber industry is responsible for land use change. Due to the possibility that the price of timber could be correlated with soybeans or cattle, it stands that an effect derived from the timber sector could be picked up and absorbed in the soybean effect.

A final limitation to the data used in the model stems from the land price data. The data, while considered to be the most accurate available, was not readily available at the municipal scale. Data points were particularly scarce in the Amazon region, which also happens to be the focus of this dissertation. To render the data into a usable format, it needed to be interpolated and recalculated in order be distributed across all of Brazil. Naturally, accuracy was lost during this process.

Several limitations are also inherent in the model itself, or of omitted variables that likely would also have wielded an impact on the results. For instance, the inclusion of both pasture area and sugarcane area as indirect drivers would have added greatly to the model. The inclusion of cattle pasture rather than actual cattle populations would have provided a better, land based variable that would be consistent with the focus of this model on changes in area. With respect to sugarcane, the expansion of sugarcane would have constituted an additional cog in the land use system, which may be responsible for a portion of displacement. In addition, this model likely captures, but does not explicitly account for, displacement tied to consolidation, as was suggested as a possible driver of contemporary land use change in the Amazon.

5.7. Conclusions and Discussion of the Results

I designed this chapter to address the first objective of this research, to provide an estimation of the so-called indirect impacts of expanding soybean production in the Brazilian Amazon. Two hypotheses were central to this objective. The first, hypothesis **H1.1**, suggested that the expansion of agricultural commodities production in Brazil has led, indirectly, to forest loss in that nation's Amazon region. The second hypothesis, **H1.2**, focused on measuring and estimating this effect. Both hypotheses were addressed through the SDM model, which, following Arima, et al. (2011), was built through an innovative weighting structure and the partitioning of Brazil's municipios into two sets. The results were suggestive of a significant and positive effect on deforestation within the Amazon stemming from changes in the extent of Brazilian soybean production.

The model results suggested a clear, indirect effect on deforestation, with the estimated elasticities indicating a deforestation response to expanded soybean production of between 1.01 (se: 0.5) and 2.29 (se: 0.32) for the partitioned and non-partitioned datasets, respectively. The higher estimate for the non-partitioned model follows logically from the specifications of the dataset. Because the non-partitioned dataset allows for the inclusion of the indirect effects of soybean production within the Amazon itself where the weighted effects are highest, the impact would be larger. Indeed this appears to be the case, though it calls into question the need to separate the direct and indirect effects, as higher deforestation in these regions may be derived at least partly from direct incursions by farmers into the forest, rather than through the displacement of ranchers or other, indirect mechanisms.

The estimated elasticities of deforestation reduction with respect to a potential decrease in the expansion of soybean production in Brazil were used to calculate deforestation reductions of between 10 and 23 percent of forest loss during the period of analysis. In real terms, these figures suggest that as much as 30,000 square kilometers of the 130,000 square kilometers of forest cover lost between 2003 and 2010 might have been driven, indirectly, through growth in Brazil's soybean sector. Confirming hypothesis **H1.1**, the results are strongly suggestive of a linkage between the expansion of agricultural production elsewhere in Brazil and deforestation in the Brazilian Amazon.

The estimations also serve as confirmation to the second hypothesis of objective, **H1.2**; that indirect land use change can be estimated. The difficulties presented in measuring spatially diffusive causality, or in this case, capturing the effects of changes occurring at a potentially large distance away, were overcome through the weighing structure and the partitioning of Brazil into neighborhoods of cause and neighborhoods of effects. With the partitioning in place the transmission of the soybean effect becomes measurable. This method of analysis offers an innovative mechanism for conceptualizing the role of distant changes and effects in driving land use change in a locality.

With the econometric results confirming hypotheses **H1.1** and **H1.2**, another set of questions arises, namely what underlying factors are driving a parallel expansion of cropland across Brazil and the loss of forests? The question is at the base of the second objective of this research, to which this dissertation now turns. The ensuing chapter seeks to engage with the indirect effects tying together soybean expansion and deforestation by approaching the issue at hand not through medium-scale statistical data, but through field work. Thus whereas the present chapter has clarified the magnitude of the effects in question, the ensuing chapter seeks to provide a clearer rational for processes and motivations from which these effects emerge. It begins in the BR-163 region, an area that has been marked in recent years by only deforestation and agricultural expansion, but also by population growth, economic development, and in-migration.

CHAPTER VI

LAND USE DISPLACEMENT AND RELOCATION IN BRAZIL'S BR-163 REGION

Where the previous chapter establishes the so-called indirect effect emanating from the expansion of soybean production, the present chapter considers the processes and spatial connections that transmit it. Here, I focus specifically on the movement of people into and out of the BR-163 region of the southern Brazilian Amazon.

This chapter and the field work that it is built from, was designed to better understand land use change and the movement of resources from the field level. It seeks, specifically, to examine the motivations underlying decisions to sell and purchase land in the Amazon, the origins or destinations of those arriving into (or departing from) the region, and land use changes that might occur after a change in proprietorship. If it can verify cases of former landowners selling their properties to relocate and expand their operations elsewhere, it can determine that the displacement of skills and capital can act in and of itself as a driver of forest loss. In effect, it seeks to better understand the spatial linkages of land use change. Not only does this work involve mapping out the extent of migration into and across the region, but it also considers the land use effects of migration as skilled ranchers and farmers both enter and exit. To this end, I conducted a survey concerning the spatial redistribution of skill and capital inputs tied to agriculture and ranching.

The chapter begins by acknowledging the changing drivers of land use and deploying a conceptual framework that draws from work in political ecology and land change science to examine migration and land use change. Here, for land use change to take place, an individual must be prepared to alter his or her production strategy, and therefore must either possess the knowledge essential for an alternative or cede control over their land to another who does. Given the overall scarcity of both human and financial capital in the Amazon, the migration of people and investments into the region thus carries a tremendous impact on land use change.

In this chapter I consider a specific region of interest, the BR-163 region of the central, southern Amazon Basin. I selected this region on behalf of its strategic positioning at the crux of the Amazon's so-called "arc of deforestation," the magnitude of growth in both cattle and soybean sectors here, and the high rates of deforestation exhibited over the past decade. If land use displacement was indeed occurring, I hypothesized that, amidst rapid growth in both the region's soybean and cattle sectors, as well as losses to the region's forest cover, it would be most visible here. I also made several preliminary visits to the region to confirm the viability of the region as a site for further study.

I have organized this chapter into three distinct sections. The first section provides an introduction to the region's economic and ecologic background, framed by a political ecology perspective on land use in the region. This section recognizes the insights and efforts of political ecologists of the past, but adopts an approach where political ecology is fused with the synergistic integrative view associated with land use or land change science (e.g. Turner and Robbins 2008, Walker and Richards Forthcoming). The subsection closes with a description of several of the variables that influence land use change in the BR-163 region. I discuss these variables in greater detail in the following sections, which consider diversity in the region's landscapes, ecology, and institutional and organizational divergences. Research has heavily documented many of the broader events underlying Amazon development in Brazil (as described in Chapters II and III), however, the Amazon, and even the BR-163 region alone, is large and diverse in both its historical development and its biophysical composition. These initial sections focus exclusively on the events and influences that shape land use change in cities along this particular highway, including the settlement patterns that provided the initial socio-economic foundations to the region's development.

The chapter then turns to the results of a field project carried forth between July and October of 2012 in western Pará and northern Mato Grosso States. This work, designed to address each of the sub questions of objective two, consists of interviews and surveys (n=54) of recent (since 2000[14]) large (>100 hectares) purchases of land in the BR-163 region. A secondary aim of this chapter, addressed in this section, is to better engage with the migration process in the region, and to understand how events and market changes taking place far from the Brazilian Amazon is driving land use change within the basin, or how they drive migration patterns. Migration into the Brazilian Amazon during earlier years largely consisted of rural-rural migration into the region from elsewhere in Brazil (Malingreau and Compton 1988, Browder and Godfrey 1997, Walker et al. 2000, Perz 2002, Moran et al. 2005, Jepson 2006a, Fearnside 2008, Jepson et al. 2010b, Caviglia-Harris et al. 2012). However, it remains less clear to what extent migration into the Amazon from outside of this region continues today; or how the Amazon's transformation into a global supplier of agricultural commodities has affected this process. Questioning recent purchasers of land in regard to their origins, resources, and reasons for migrating provides some insight into how farmers or ranchers immigrating into the region come to their decisions to reinvest their skills and capital here.

Field results are discussed in the final section, which stresses the interregional linkages driving land use change in the BR-163 region. This section closes by acknowledging the rising

[14] One survey recorded a migration to the region in 1995, and has been included in the analysis.

role of the Mato Grosso soybean complex as a self-sustaining driver of Brazil's Amazonian economy.

6.1. Land Use and Landscape: The Cuiabá-Santarém Corridor (Federal Highway BR-163)

This dissertation builds from field work conducted in seventeen Brazilian municipios, each transected by BR-163 or closely connected to the highway and reliant on it as a principal transportation axis for local produce (figure 6.1). The entire BR-163 corridor, which links the cities of Cuiabá and Santarem, transects more than 1,100km of the southern Amazon Basin. A 750km sub-segment, stretching from Lucas do Rio Verde and Sorriso in the south, to Morães de Almeida, a village within the municipio of Itaituba to the north, in western Pará, was selected for analysis. While the region is homogenous in its dependency on BR-163 and its prolific extent of land cover change, it is varied in its biophysical and socio-economic dimensions.

In this section I situate these differences within a longstanding geographic tradition of regional analysis, where divergences in both human activity and landscapes are tied to human environment interactions. This approach, drawing on a history of geographic analysis dating back to Carl Sauer (1925), views landscape as an ongoing, *phenomenological* process, where complex social and natural phenomena interact to form and reform (Price and Lewis 1993, James 1969). It begins by recognizing the work of political ecologists, and considers land use and the region's landscapes, fusing this work with that of land change science. Here I suggest that local actors and organizational structures have been fundamental to the creation and recreation of a landscape of agriculture, ranching, and forest, but also acknowledge that these entities and agents operate within a broader system of institutions and regulations. I also take a step forward to suggest that local level decisions are not only relevant to the landscapes in one location, but also to those in other, potentially distant locations. After an introduction to the political ecology perspective, I proceed to a description of the anthropogenic and natural landscapes of the BR-163 region; I follow this, in turn, with a second sub-section considering the settlement processes and institutions that are integral to shaping many of the present-day organizations in the region. I close by suggesting that the skilled labor necessary for agricultural or beef production will be drawn to regions with favorable institutional and ecological qualities.

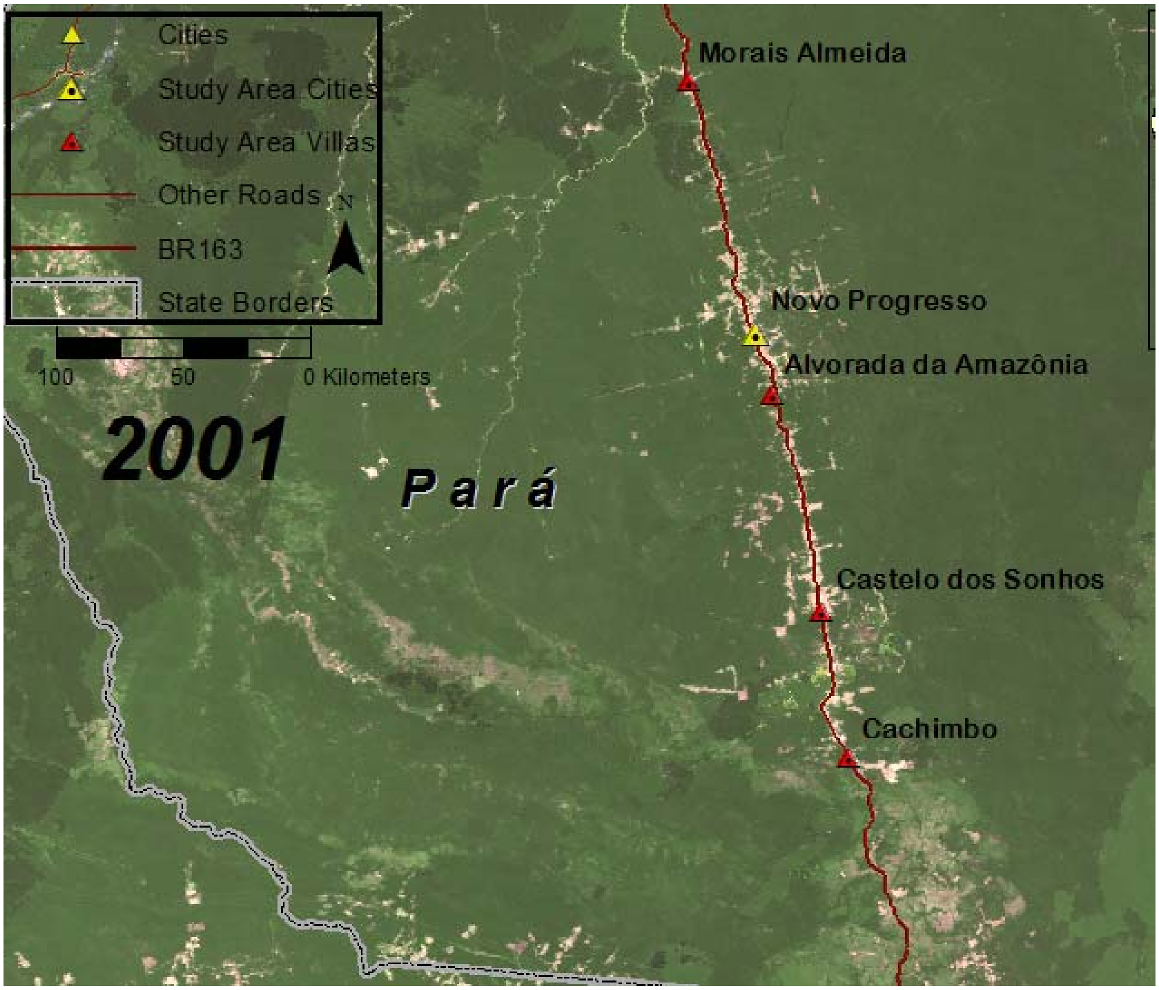

Figure 6.1(a). Map of the BR-163 Region. *BR -163 region in Pará*

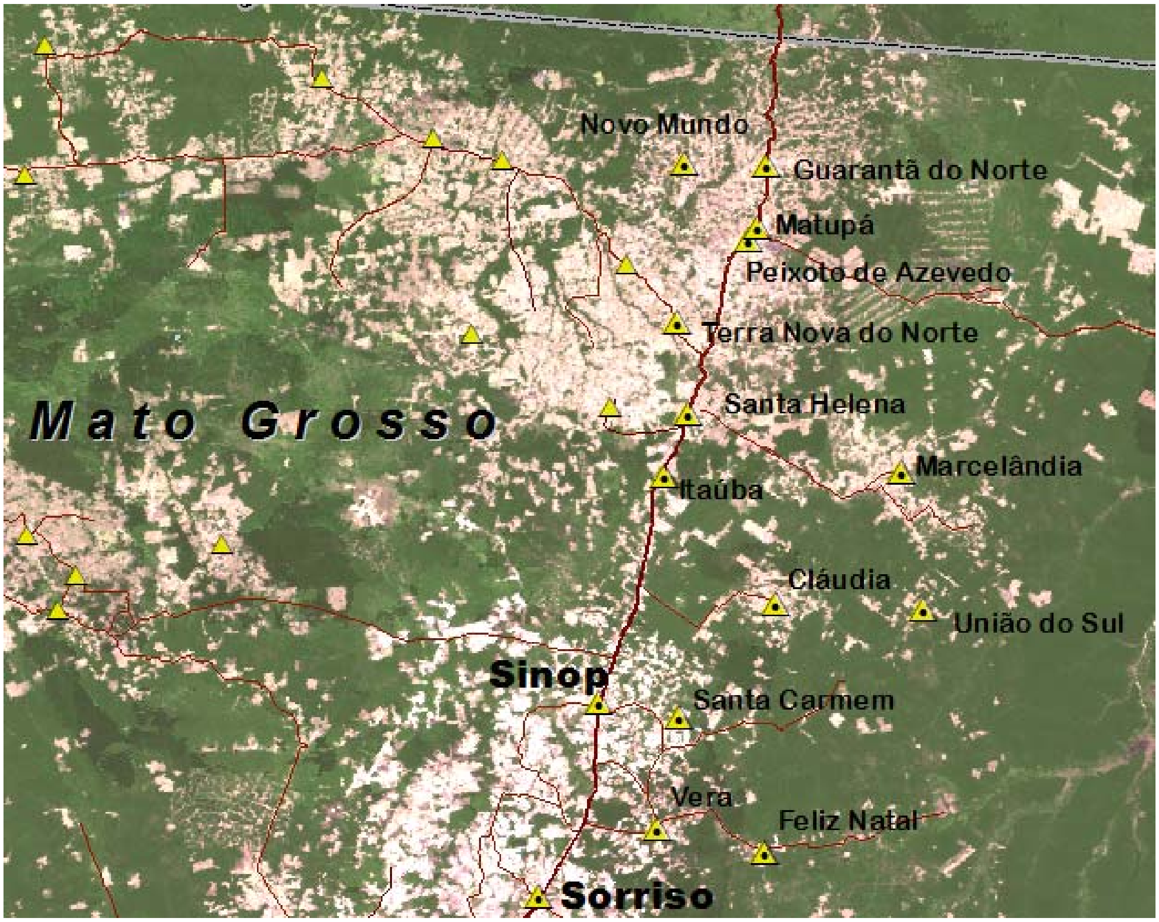

Figure 6.1(b). Map of the BR-163 Region . *BR -163 region in northern Mato Grosso*

6.1.1. Framing a political ecology approach to land use change in the BR-163 region

This section provides an introduction to land use and economic change in the BR-163 region of the central Amazon, drawing heavily from the field of political ecology. Political ecology emerged in the late 1980s and early 1990s as social scientists (likely following the public at large) shifted their interests away from development studies and towards issues of environmental sustainability (e.g. Turner et al. 1990, Meyers 1980). For political ecologists, this shift in focus required not only reconsidering the role of institutions in shaping welfare outcomes, but also in shaping the environment at large. The approach calls far back into the annals of geographic analysis, and emanates from the initial work of Sauer (1926) on cultural landscapes. It recognizes the importance of historical forces and past relations with nature as acting to create and shape both society and the landscapes that it manages. In particular, political ecologists have taken up the torch of Sauer's emphasis on field work, and his rejection of a positivist assertion of clear cause and effect in the face of complex, multi-faceted interactions between people and their environment.

Blaikie and Brookfield and their seminal volume, Land Degradation and Society, offered an integrative economic, ecologic, and political perspective on environmental change in Nepal (Blaikie and Brookfield 1987). They explicitly recognized the importance of spatial and neoclassical economic structures in their analytical perspective. Yet they also made it clear that the diversity of drivers of land degradation in different places would render any search for a single causal factor underlying the issue bound for futility. Rather, they suggested, researchers must recognize the importance of place, and of understanding how a complex array of forces tangle to form a landscape. Land use and land degradation is thus better viewed as a dynamic expression of forces reflecting both history of place and an evolving set of structural conditions.

In essence, it goes to suggest that while people are constant, the forces that shape their behaviors are temporary. The subfield that has subsequently emerged around political ecology has since repeatedly called attention to the role of institutions and social forces as drivers of environmental degradation (Zimmerer and Bassett 2003, Robbins 2004) and for a greater emphasis to be placed on understanding the importance of "place" (Massey 1994).

Political ecology framed studies of land degradation in the Amazon Basin have been principally concerned with deforestation. Studies in the Brazilian portions of the basin suggest close ties between deforestation and national institutional structures, whether of the military government or the neoliberal republic that followed. More specifically, this work suggested that deforestation was linked to subsidies offered to large scale ranches or corporations seeking to offset losses in commercial or industrial ventures through government incentivized tax havens in the Amazon Basin. Early work by Hecht (1985), Hecht and Cockburn (1989) , Branford and Glock (1985), Bunker (1988) and Browder (1988), for example, all linked sharp increases in deforestation and violence in the Amazon to the nation's tax policies (or the enforcement thereof, in the case of capital gains) and structural incentives for deforestation. Not surprisingly then, political ecologists pointed to tax reform as a means by which to address forest loss in the Brazilian Amazon (Moran 1993). One glaring shortcoming of political ecology studies in the region during this period, however, was the clear omission of field work directly addressing larger scale operations. Rather, much of the initial field research in the Amazon included work with smallholder or indigenous communities, but pointed toward large scale ranchers and crony capitalists, abetted by national tax structure built by politicians in their favor, as a primary cause of deforestation in the region (e.g. Ianni 1979, Foweraker 1981, Schmink and Wood 1992). And while it is likely indisputable that state policies of the 1970s and early 1980s did redirect capital into the region (as was planned), many more arrived without financial assistance from Brasília (Walker et al. 2009a). Not surprisingly then, the reformation of the Amazon's development policies in the 1980s and 1990s, which included the removal of many of the former state sponsored subsidies in the region, failed to halt the region's forest loss.

Much of the early political ecology work in the Brazilian Amazon, as well as more recent research on land use change in the region, has proved more fruitful in unpacking the relationships between large ranches and smallholder farmers, or in unpacking the tension and violence that emerged over land. Work on contentious land use change in the Amazon, present in the initial political ecology studies in the region, has since continued to proliferate. For example, geographers such as Wolford (2003), Simmons (2007) and Aldrich (2011) have situated smallholder land use decisions within a socio-economic environment defined and dominated by a class of economic elite. Their incorporation of large scale producers and producer organizations directly into political ecology analysis is a step toward including these agents in such an analytical framework. This has continued as soybean and beef producers have garnered more attention and are increasingly linked to land use change in the region (Jepson et al. 2010a, Brannstrom 2009, Brannstrom et al. 2008, Nepstad and Stickler 2008, Brown et al. 2007, Hecht 2005, Brandão, Rezende and Marques 2005). Nevertheless, it has become evident that this class of agents remains comparatively less understood.

Though still infrequent, several researchers have explicitly analyzed the structures and organizations of capitalist farmer. Notably, Jepson (2010a, 2006b, 2006a) produced several influential articles on the organizational structures of commodity producers in northern Mato Grosso, suggesting that the cooperative structures of privately organized colonization schemes were fundamental to their development. Her research indicated that the delineation of clear property rights in these settlements at the time of occupation, in addition to a tradition of working cooperatively and disseminating ideas in difficult frontier environments, was critical to the success of commodity farmers in the Amazon. To some extent, the tradition of strong social networks draws from the socialist and cooperative leanings of the former Atlantic Forest frontier areas of southern Brazil.[15] Many of the colonization cooperatives responsible for agricultural settlements in Mato Grosso, for example, were offshoots of cooperatives already established in the south (Jepson 2006a).

In his unpublished dissertation Adams offers another perspective on soybean farmers (Adams 2008). By focusing on cultural perceptions of land use their and relationships to nature, Adams suggests that soybean farmers, many of them "Gauchos" from the southern State of Rio Grande do Sul, represent a faction separate from the traditional landed elite. Whereas these *Gauchós* viewed land as a production input, and were closely involved in the day to day operation of their farms, the legacy owners of *latifundia*[16] ranchers viewed their parcels as investments, as a status symbol, or as part of a broader economic portfolio.

Past insights also point to the importance of understanding the market structures that drive land use change. Land use decisions by commodity producers reflect these shifting structures; and it is imperative to situate local practices within this context. Accomplishing this feat, however, requires scaling out from the local level, a longstanding issue for political ecologists, who have at times been "trapped" in their preference for local, grass roots solutions

[15] Socialist and social movements have long had a strong history in Brazil's southern states. Brazil's landless movement, the MST (*movimento sem terra*), for example, was founded in Rio Grande do Sul. President João Goulart of the Brazilian Workers Party (PTB) and who was later deposed by coup d'etat in 1964, was also a native of Rio Grande do Sul.

[16] *Latifundia* refers to large rural properties, often with a connotation towards an inefficient land use system dominated by a small group of elite landowners.

(Loveland et al. 2000, Brown and Purcell 2005). Nevertheless, this recognition of the inter-regional and even inter-continental linkages between decisions made within the Amazon and distant choices in consumption, investment, and regulations has prompted a number of researchers to expand the scope of their analysis. Walker, et al. (2009a), for example, broaden the scale of the political ecology perspective on land use change and deforestation in the Amazon to recognize its changing political and economic structures and its reorientation towards producing for international markets. Such work is representative of an increasingly common, if still infrequent, movement towards fusing the sub-fields of political ecology and land change science.

Despite obvious differences in political ecologists' and land change science researchers' methods, motivations and interpretations of the causes and consequences of land use change, the two groups share several points of interest. A common recognition of the complexity of land use change and its ties to place, as well as a focus on reading the drivers of environmental change as they occur within an intricate system of social, political, and economic forces, for example, are two areas where political ecology and land change science are joined (Turner and Robbins 2008). This research adopts a similar, integrative approach that is reflective of these areas of overlap. It considers land use change as driven by decisions made at the farm level, but does so by placing decisions within a systemic structure of factors and influences operating at multiple scales. It acknowledges both vertical and horizontal linkages across scale; and thus not only recognizes the importance of local organizations and institutions, but also that even local-scale decisions made in potentially distant regions may wield an important impact on local level decisions in the Amazon.

6.1.2. A political ecology of agriculture and capital in the BR-163 region

An integrative land change science and political ecology approach sheds additional insight into the factors that influence land use and deforestation outcomes in the region. This dissertation has attempted to document many of these factors at various points in this and the preceding chapters. Summarized in table 6.1, they range in scale from the local to intercontinental levels, and can be categorized as social, political-economic (or institutional), ecologic, and economic.

Table 6.1
Organization of Factors Influencing Land Use in the BR-163 Region

	Local	State/Federal	Inter-Continental
Labor/Social	• **Labor Skills & Experience** • **Farm-Level Access to Capital** *(Brown, et al.2004)*		
Political Economy	• **Land security** *(Alston, et al. 1999)* • **Land Availability/ Dist.** • **Cooperative Organizations** *(Jepson, et al. 2010a)* • **Trade Organizations**	• **Land Tenure** • **Policy & Enforcement** • **Sector Lobby & Influence** • **Access (Infrastructure)** *(Walker et al. 2009a)* • **Forest Reserves**	• **NGOs & Environmental Regulations** • **Trade Agreements** • **International Demand**
Ecology	• **Soil Fertility** *(Carvalho et al. 2009)* • **Precipitation** • **Topography** • **Biomass & Density**	• **Ecological Advantages (Regional)**	• **Ecological Advantages (International)**
Economy	• **Transportation Costs** *(Pfaff 1999)*		• **Commodity Markets**

a. Economy. This dissertation has focused heavily on the economic incentives underlying production decisions. The roles of commodity markets and farm level prices, for example, occupied a pivotal position in the utility framework developed in the earlier chapters, while the Thünian rent structure situated these incentives within a spatial structure that placed soybean production closer to points of consumption and cattle ranching in more distant locations (Walker and Richards Forthcoming, Walker et al. 2009b).

b. Ecology: Land quality affects what land can produce, and spatial variation in land quality influence production locations. In the Amazon Basin and along the BR-163 region the landscape varies tremendously in soil type, topography, precipitation, natural land cover, and latitude. Both ranchers and farmers prefer more fertile soils, flat lands, and lower levels of vegetation. For farmers, soil quality, nearly always needs correction through fertilizer application. Farmers do, however, generally prefer clayey soils to sandy varieties. Topography is essential, given the limitations to the mobility of planting and harvesting machinery (USDA 2007). Discussions with key contacts in the soybean sector suggested that farmers seek land with a grade of less than ten percent. The gradient is significantly less than slopes used in the soybean regions to the south, but reflective of the larger and less agile machinery employed in Mato Grosso. Lands that may be suitable for ranching may never be suitable for agriculture.

Precipitation and access to water is essential for both soybean producers and ranchers. For ranchers, year-round access to water is required to sustain a cattle herd. Given the seasonable nature of rains in much of this region, many water sources disappear in the dry months. Consequently, without investments in pumps and wells, ranching is not necessarily viable in drier or upland locations. Conversely, soybean production only requires access to water during the planting season and is likely to face fewer limitations in this regard. The regular and predictable rains during the rainy season, in fact, are highly favorable to crop production. Irrigation in the region remains uncommon, but where installed, farmers are able to reap up to three harvests per year.

Vegetation density continues to pose an obstacle to both ranchers and farmers, as its very existence precludes the use of the land for commodity production. Clearing vegetation represents a cost, or an investment prior to production. Logically, the cost of clearing is related to the density of the biomass on a piece of land, which tends to be less in areas of cerrado, medium in the areas of transitional forests, and highest in humid portions of the region. Rent seeking landowners often seek a least cost path to land clearings, and many of the most accessible and less dense forest regions have already been cleared. In the southern portions of the BR-163 region, forest cover is less dense, making the regions more susceptible to clearing, while those farther north are comparatively intact. While the cost of clearing certainly presents an obstacle to the expansion of both ranching and farming, the larger obstacle in this regard is likely a political one, as will be described in the next subsection.

c. Political Economy: In Chapters II and III I discussed many of the political economic factors that influence land use change in the Brazilian Amazon at length. Several of these factors merit special recognition in regard to their impact on production in the BR-163 region.

Land security has played an important role in discussions of land use and deforestation. The Brazilian constitution's infamous requirement that land be employed in a productive state for secure ownership, for example, is often cited as a driver of deforestation and contentious land use change (Aldrich et al. 2011, Caldas et al. 2007). This is counter to some theories from neoclassical economics, which may view secure land tenure as essential for investment. Absent a guarantee of land ownership, land owners are less likely to invest in their properties and, given that deforestation is a form of investment, deforestation would remain low. Once the right to open more land for production is clear, the owner may then harness outside financing and increase their capacity to clear additional lands (Alston et al. 1999).

Soybean producers especially value more secure tenure, given the levels of investment required for production (Brown et al. 2004). For ranchers, the effect is unclear, as insecure land tenure may ease the potential liability associated with illegal or unauthorized clearings. Cattle production also requires minimal investment, meaning that land security may not be a prerequisite for production. In any case, in many of the cattle regions of western Pará authorities have issued only a few titles, and landowners continue to shop the only documentation that they possess, typically a certified “right to possession” card. As a general rule, property rights in the BR-163 region tend to be clearer in privately settled counties such as Sinop and Sorriso than in the less organized settlements in western Pará. In this dissertation I view the property rights pre-established in privately settle colonization projects as a fundamental underlying cause to their development into agricultural districts.

Another issue of interest to both soybean farmers and ranchers is access to land. The distribution of land varies immensely across the BR-163 region. Districts in northern Mato Grosso, including much of the counties of Guarantã do Norte, Peixoto de Azevedo, and Novo Mundo, include both latifundia ranchers and smallholder properties. In the principal agricultural zones, latifundia farms predominate in some counties, such as in Sorriso, where farms of 1000 square kilometers are relatively common, but are sparse in others, such as in nearby Sinop, where farms are comparatively smaller owing to the initial distribution of land and the need to maintain a larger forest reserve.[17] The atomization of land distribution poses a particular problem to

[17] Based on observations and discussions with key industry representatives.

soybean farmers, as production requires a larger scale to meet the financial costs associated with mechanization. For ranchers, this is less clear; however, discussions with ranches in the region have generally suggested that a successful ranch owner will try to maintain a herd of at least 600-800 head of cattle, implying a need for parcels of at least 10 square kilometers.

Community organizations and institutions also present an important element in creating a favorable foundation for commodity production (Jepson 2006a, Jepson 2006b). As indicated in the previous chapters, the creation of efficient cooperative institutions in regions of Mato Grosso resulted in an environment favorable to expansion. Based on my discussions with farmers in northern Mato Grosso, it was clear that they saw their region as being at the forefront of the sector in the adaptation and dissemination of agricultural technologies in Brazil. The region has a history of adaptation, a trend that owes, in part, to the legacy of strong trade lobbies and trade organizations. The nature of these organizations, however, varies tremendously across the BR-163 region; they tend to be strongest and more organized in Mato Grosso and weak in western Pará. Organizations such as FAMATO, ACRIMAT, and APROSOJA are present in nearly every municipio in Mato Grosso. In contrast, in Novo Progresso and Castelo dos Sonhos, the organizations representing producers, The Vale dos Garças Organization and Association of Rural Producers of Novo Progresso, for example, appear to operate independently from any larger institutional structure.

c. Labor/Social: Residents' skills and the availability of local knowledge is the final category in table 6.1. For land use change to take place, the knowledge of how to use land must first be present. Along the BR-163, the skills of migrants into the region varies widely. Arguably, the arrival of prospectors and smallholder farmers into western Pará and areas of northern Mato Grosso, mainly from the northeast, brought the institutions and producer relations of the northeast to the BR-163 region and resulted in a system of large ranches and semi-subsistence agriculture and semi-extraction. In Sinop, a city that was initially dominated by timber production and founded primarily by arrivals from the former Atlantic Forest frontier region of northwest Paraná, a mixture of medium sized properties emerged around a planned urban core. Just farther south, better capitalized farmers from Rio Grande de Sul flocked to Sorriso, where they imported early technologies in large scale agriculture into the region. In each of these areas, the present day structure of production suggests close ties to its historical settlement patterns.

Evidently, the skills and knowledge associated with those who migrate into a region has is a key factor behind landscape creation in the Amazon; and the distribution of present day production strategies and institutions is reflective, in part, of those who settled there. The migration linkage constitutes a unique, horizontal linkage between land use change and landscape in one location and land use change and landscape in other, potentially distant locations. Recognizing these local level, spatial connections is essential when considering the drivers of land use change. In the following sections I provide a broader description of the landscapes and institutions that have emerged in the BR-163 region. I designed these sections to provide a more complete introduction to the economic, institutional, and biophysical context to the field results.

6.1.3. Ecology and landscapes

Just as with the broader Amazon Basin, the topographies, precipitation levels, and natural land covers specific to the BR-163 region are diverse. At the southern end of this area the low and dense scrub forests of the cerrado, a biome typical of central Brazil, dominate; but as one travels northward toward the Amazon River the forest becomes increasingly humid. Here, the scrub forests of the cerrado give way to denser transitional forests and later, the moist tropical forests most often identified with the Amazon rainforest biome. Rains in the cerrado areas and the transitional forests of Mato Grosso are highly seasonal, but also highly predictable, with the wet season occurring between October and April and a dry season during the remainder of the year. Outside of the rainy seasons rains of any magnitude are extremely rare. The predictable precipitation during the rainy season removes some of the risk of agriculture; and farmers here, particularly in those counties composed of cerrado vegetation, have largely escaped the occasional droughts that plague agricultural production elsewhere in Brazil. Given the cerrado's favorable precipitation, its relative ease of clearing (as opposed to moist forest), planar topography, access to markets and ports in the nation's south, as well as legal advantages for clearing land,[18] soybean production dominates in southern portions of the study region. The counties of Sorriso and Nova Ubiratã are positioned at the southern extreme of the study area and largely composed of cerrado vegetation, for example, host the highest concentrations of agriculture in the study region. Sinop lies directly north, at the transition point between cerrado and moist tropical forest.

Sinop, founded in the 1970s through a private colonization initiative, is the largest and fastest growing city in the study region and among the fastest growing in all of Brazil. Once heavily dependent on the timber industry, over the past decade the city has transitioned into an agricultural capital, with soybean production expanding rapidly here after the advent of the soybean boom at the turn of the millennium (Santos 2011). North of Sinop the landscape transitions from agriculture to degraded pasturelands, with the omnipresent silage facilities of

[18] Brazilian environmental law permits up to 65 percent of a property to be cleared within areas of cerrado , as opposed to 20 percent in areas of tropical moist forest.

farther south becoming increasingly common. The forest return to the margins of BR-163 after the city of Guarantã do Norte, or as the road begins its traverse over the shoulder of the *Cachimbo*[19] mountain range, a highland area of sandy soils, waterways and scrub forest at the border between Mato Grosso and Pará. This area resembles, in many respects, the cerrado of farther south, and is protected by a battery of parks and policies that includes a biological reserve, a national forest, and a remote military base that once housed Brazil's clandestine nuclear projects *(Instituto Chico Mendes 2012)*.

In the State of Pará the forest becomes increasingly moist and its strands loom larger. Here the terrain is hillier than farther south, and its undulating and rocky surfaces stand in contrast to the flat plains of northern Mato Grosso. Historically, the increased precipitation here and the treacherous terrain have combined to make roads impassable during the rainy seasons. And until the past few years, nearly 800km of BR-163 remained unpaved, including a large segment between Guarantã do Norte and Triarão.

Owing to the difficulties of reaching the area, western Pará has historically been extremely isolated. Castelo dos Sonhos, a villa officially located in the municipio of Altamira, is located more than 1,000km away from its municipal government. Novo Progresso only emancipated and declared independent in 1993, was for many years under the jurisdiction of the city of Itaituba, nearly 500km to the north.[20] To this day, the village of Morães de Almeida, slightly north of Novo Progresso, remains under the jurisdiction of Itaituba, five to six hours travel away (previously more), not including ferry passage across the mighty Tapajós River. In addition to being isolated from municipal government offices, the entire region is also located far

[19] Cachimbo translates as pipe in Portuguese, an name reminiscent of the volcanic center.
[20] As calculated in Google Maps

from the state capital, Belém, located 2,000km away, or more than two days of driving. Owing to its remoteness, federal offices and controls have also been traditionally absent in the area. Despite the region's environmental value and the prolific nature of the timber industry here, only in the past decade were the first IBAMA agents, and by proxy, the first locally-based federal offices, based in the region. With the asphalting of BR-163, however, government agents have become less avoidable, and traditional state and municipal institutions have begun to supersede local power structures.

In much of western Pará the Amazon forest remains largely intact. However, as access (or the expectation of new access) improves and as rents for beef production increase and land values rise, deforestation continues. In the past decade, Novo Progresso, areas around Castelo dos Sonhos, and other tracts alongside the BR-163 region in Pará have become fulcrums in discussions waged by environmentalists and economic interests concerned with the region (Bernardes 2007, Monié 2007, Fearnside 2007, Hecht 2011, Soares-Filho et al. 2004). To stave off additional deforestation tied to the paving of BR-163, the national government created a series of protected areas in the region. This includes, among others, the Jamanxim National Forest (FLONA Jamanxim) and the Cachimbo Biological Reserve (REBIO Nascentes do Cachimbo), both of which were created in 2006 (Instituto Chico Mendes 2012). While these protected areas have done much to reduce deforestation within their boundaries, deforestation rates remain high in western Pará, with levels of forest loss in the three western counties of Itaituba, Novo Progresso and Altamira regularly ranking among the highest annual deforesters each year since 2004 (INPE 2011). Although the topography will probably preclude large scale agriculture in much of the region, some of those whom I interviewed suggested that the rich soils and plentiful rainfall of the region make it highly suitable for production, particularly in flatter areas. As one interviewed rancher memorably described the region, the area is the “Filet (Mignon) of Pará”. The future of this “filet” from both a social and ecological standpoint is at a crucial juncture, and the paving and improvement of BR-163 will bring both new opportunities for the region and a potential impetus for widespread land use changes.

6.1.4. Early inhabitants, institutions, and economy

Few details are known in regard to the first inhabitants of northern Mato Grosso and western Pará. However, the Caiapo, who now occupy much of the Xingu region lying to the east of the study area, arrived to the area after displacement from the cerrado by encroachment of settlers of European descent in the 18th and 19th centuries. Other indigenous groups, notably the Kraee Aka Rore-Panará, who resided on the banks of the Peixoto de Azevedo River near Guarantã do Norte and Peixoto de Azevedo, likewise arrived from the scrubland cerrado forests to the east. Many of the indigenous inhabitants of the region saw their populations drop after the creation of the road. The federal government later relocated their remaining populations to within the boundaries of the nearby Xingu indigenous reserve, one of the first indigenous areas in the Brazilian Amazon (Santos 2011).

While it is likely that early rubber tappers at one point explored or temporarily inhabited some of the tributaries that crisscross the present day BR-163, the settlement of the region by Brazilians of Afro or European descent commenced with the construction of BR-163. Plans for BR-163 were initiated in 1971, and by the following year colonization companies began plotting out new cities and settlements along its presumed route (Santos 2011). As with much of the Amazon, the occupation of the BR-163 region took place through three principal mechanisms: (1) spontaneous arrival and occupation (Aldrich et al. 2011, Caldas et al. 2007, Simmons et al.

2007); (2) public colonization projects administered by the Institute for Colonization and Agrarian Reform (INCRA 1978, Browder 1988) ; and (3) privately organized colonies, where cooperatives or private enterprises were employed to administer the distribution of planned lots in projects approved by INCRA (Jepson 2006a, Jepson 2006b).

Colonization in the BR-163 region, just as in many places in the Amazon, involved tremendous hardship for many of those who came to settle here. Malaria, hepatitis, airplane crashes, and frontier violence could and did break apart families (Oravec 2003); there was little or no access to health care or outside assistance, and little recourse in times of emergency. Colonization projects, and particularly those engineered through private or cooperative ventures, provided some level, even if minimal, of structure and security to both the person and property of those arriving to the region, offering these areas important advantages over publicly or spontaneous areas of colonization (Alves 2003).[21]

Evidently, privately administered colonization projects were far more prolific in Mato Grosso than in Pará. Of those projects carried forth across Mato Grosso between 1964 and 1981, every colonization program was administered by a private company, in total settling nearly 9,000 families on slightly less than 20,000 square kilometers of land (INCRA 1978). In Pará during this period, the opposite occurred. Prominent *Integrated Colonization Projects* (PICs), involving the simultaneous settlement of urban and rural areas, were installed in Altamira, Marabá, and Itaituba, with each settler promised a lot with road access, six months of subsistence wages, and a wooden house (Wesche 1974). Of the nearly 40,000 square kilometers of land in Pará

[21] The few exceptions include Peixoto de Azevedo, a prospectors' boom town that developed spontaneously in the 1980s, and INCRA planned colonies in Novo Mundo and Guarantã do Norte, which was used in part as a location to resettle *Brasiguaios* (Brazilians living in Paraguay) freed from slave labor conditions in eastern Paraguay.

distributed via projects to 8,700 colonist families, 36,000 square kilometers were destined to 6,200 families through public colonization projects (INCRA 1978, Santos 1985). No public colonization projects or private initiatives were present in the areas of western Pará critical to this analysis (INCRA 1978).

In many cases settlers arrived to private colonization projects with at least a minimal amount of capital, or at least capital sufficient to purchase property; they also boasted easier access to credit, with the projects acting both as boosters for outside investors and as intermediaries to the federal bureaucracy; private colonization projects in particular appeared to have been better organized and more capable of capturing federal financing for public infrastructure projects such as agricultural silage, health facilities, and electrification. Evidently, private colonies were able to clear more land, and do so at faster speeds than their publicly organized counterparts (Jepson 2006a, Jepson et al. 2010b). Today, counties founded through private colonization schemes boast certain advantages over other regions, including clear property lines and title rights and, in some cases, some of the highest human development indices (HDI) seen in the Amazon. In 2000 Sorriso, Lucas do Rio Verde, Claudia, and Sinop, all privately colonized, ranked among the highest counties in the Legal Amazon in terms of HDI (PNUD 2001).

In the BR-163 region of western Pará the patterns underlying settlement are less clear. There is no evidence, however, of any settlements emerging through planned project initiatives. Rights to occupy land were issued directly from INCRA to individual owners,[22] and the settlements that emerged in the region, including at Castelo dos Sonhos and Novo Progresso, emerged as clusters around early trading houses and fuel stops. Many of the settlers that came to

[22] As described through key informant interviews with early colonists in the region.

the region arrived not with official rights to land, but rather only with an intent to occupy or to claim unoccupied or undefended properties (Oravec 2003). The lack of planned settlement projects here, combined with a near absence of land tenure without clear occupation, likely contributed to the continued ambiguity of property ownership and the intractability of frontier violence. The already chaotic institutional structure also provided a fertile ground for the ongoing processes of land grabbing and land occupation, processes further complicated by the discovery of gold in rivers such as the Curúa (near Castelo dos Sonhos) and the Jamanxim (near Novo Progresso).

In the 1980s, prospectors, primarily from the northeast, converged on western Pará, fueling a boom that transformed tiny communities anchored by a chapel and a football pitch into bustling towns. The growth in gold production, and the capital which it quickly attracted to the region, gave rise to Wild West like personalities and boasted nationally known characters such as Marcío Martins, the Rambo of Pará, notorious for their violent grip over the region's prospectors (Oravec 2003). While the hustle of the gold panners and the wealth created through the mineral's extraction would prove ephemeral, the mark on the region would prove to be anything but. Only in the past years, as the asphalt has crept closer to Novo Progresso and Castelo dos Sonhos, has the once indelible frontier character of these towns begun to be shed.

Table 6.2
Genesis of Selected BR-163 Municipios

Municipio	**State**	**Settlement Mechanism**	**Settlement Company/Agency**	**Year of Settlement**
Sinop	MT	Private	Sociedade Imobiliária Noroeste do Paraná	1972
Vera	MT	Private	Sociedade Imobiliária Noroeste do Paraná	1972
Itauba	MT	Private	Timber Companies	1973
Sorriso	MT	Private	Colonizadora Feliz	1977
Marcelandia	MT	Private	Colonizadora Maiká	1977
Terra Nova do Norte	MT	Private	Cooperativa Mista de Canarana	1978
Nova Santa Helena	MT	Private	Sociedade Imobiliária Noroeste do Paraná	1978
Claudia	MT	Private	Sociedade Imobiliária Noroeste do Paraná	1978
Guarantã do Norte	MT	Private/Public	Cooperativa Tritícula de Erechim Ltda./INCRA	1979
Peixoto de Azevado	MT	Spontaneous/Public	Spontaneous	1979
Santa Carmem	MT	Private	Sociedade Imobiliária Noroeste do Paraná	1981
Novo Mundo	MT	Public	INCRA	1981
Matupa	MT	Private	Colonizadora Agropecuária do Cachimbo	1984
União do Sul	MT	Private	Colonizadora Paralelo 16	1982
Feliz Natal	MT	Private	Agropecuária Companies	1987
Nova Ubiratã	MT	Private	Comércio de Imóveis Pinheiro Ltda.	Unclear, ~1987
Novo Progresso	PA	Spontaneous	Spontaneous	From ~1977
Castelo dos Sonhos	PA	Spontaneous	Spontaneous	From ~1977

Agriculture arrived to the BR-163 region with colonists arriving from the southern states of Rio Grande do Sul, Santa Catarina, and Paraná. Early attempts to produce coffee, rice, soybeans, and manioc here proved less than successful, however, owing both to the inaccessibility of the region, and to the difficulties of planting temperate and subtropical crops in the tropical climate and acidic soils of the northern cerrado and the Amazon. Mechanized rice production did exist as early as in the 1980s in Sinop, with producers taking advantage of national price supports and minimum pricing policies (Santos 2011). During this period immigrants to Mato Grosso were also working to develop strains of soybeans better suited to the shorter daylight hours of the tropical latitudes (Warnken 2002). By 1990 they had achieved a measurable level of success; and the crop was becoming commonly planted in regions of the state, including the southernmost counties of the BR-163 region.

With the spread of new seeding and planting technologies and the implementation of the neoliberal economic reforms put in place in the early 1990s, soybean producers rapidly expanded their production (IBGE 2011a). From 1990 to 2000 the area of soybean production tripled in the BR-163 region, from 1,535 square kilometers to 4,758 square kilometers, with 90 percent of the soy planted here taking place in Sorriso or neighboring Nova Ubiratã. From 2000 to 2010, the area of soybean production within the BR-163 would again (nearly) triple, reaching more than 12,000 square kilometers (with approximately 70 percent of the planted area in Sorriso or Nova Ubiratã). As the crop became more profitable, farmers expanded northward from Sorriso and west and eastward from BR-163. Growth in planted soybean areas in cities such as Sinop (+1,005 square kilometers, 13% of the region's planted area), Vera (+1,110 square kilometers, 14%), Santa Carmem (+452 square kilometers, 6%), Feliz Natal (+447 square kilometers, 6%), and Cláudia (+403 square kilometers, 5%), suggests that soybean production was occurring at the expense of other land covers, including pastures and tropical forests (IBGE 2011a).

As the soybean industry took hold in the southern portion of the BR-163 region, the cattle sector grew prolifically in counties slightly farther north. In the Mato Grossense portion of BR-163, the cattle population doubled between 1990 and 2000, from 470 thousand to over a million head. Between 2000 and 2010, it doubled yet again, to 2.1 million. Of the cattle stocks located in the 14 municipios of interest in Mato Grosso, nearly two-thirds were grazing in the most northern municipios in the state: Guarantã do Norte (18%), Itaúba (16%), Marcelandia (11%), Matupa (9%) and Peixoto de Azevedo (10%). During the last decade, most of the growth in the region's cattle herd occurred in the most northern municipios, and in more marginal counties located east of highway, near the Xingu reserve. Between 2001 and 2010, Guarantã do Norte (+112,723, 13% of total herd increase in MT BR-63 region), Marcelandia (+93,741, 10%), Novo Mundo (+281,617, 32%), and Peixoto de Azevedo (+138,834, 16%) saw the largest increases (IBGE 2011b).

In Pará, the increase in the region's herd cattle is more difficult to calculate, as much of the area is located within the jurisdictions of Altamira and Itaituba, two very large counties which include extensive areas located far from BR-163. Because statistical data collected at the municipio level fails to discern between districts such as Castelo dos Sonhos (of the municipio of Altamira) and Morães de Almeida (municipio of Itaituba) from the remainder of these counties, it is difficult to fully estimate the growth of the cattle sector here. However, Novo Progresso, established as a municipio out of Itaituba in 1993, provides some insight. From 1993 to 2000, Novo Progresso's cattle population grew by 70,000 animals, to over 150,000 head of cattle. From 2000 to 2010, however, the cattle herd had quadrupled, to over 636,000 head, a total that equals more than half of the increase in the BR-163 region in northern Mato Grosso (IBGE 2011b).

As might be expected, cattle require land; and deforestation has accompanied the growth in cattle production. Between 2000 and 2010, forest cover in Novo Progresso declined by 3,000 square kilometers; in Altamira, by 4,700 square kilometers, and in Itaituba, by 1,500 square kilometers. In Mato Grosso, where the municipios are much smaller, Nova Ubiratã, Peixoto de Azevedo, Feliz Natal and Marcelandia, all with their own frontiers on the fringes of the Xingu reserve (Brazil's largest indigenous territory in Mato Grosso), likewise compiled high levels of deforestation during this period (INPE 2011).

The BR-163 region has recently become an area of contention, largely owing to disputes over whether or not to complete the 800 kilometers segment of the road that (until recently) remained unpaved. The decision to pave the road was encouraged by a move in 2002 by Cargill to establish a deepwater port on the Amazon River from which to supply non-genetically modified soybeans to consumers in Europe; the move set off a firestorm of environmental criticism. Economically and geographically, locating a deep water port at Santarém appeared to be a sensible development plan, and the idea was pushed forward, in part, by the mayor of Santarém (Weinhold, Killick and Reis 2011). It wasn't lost on soybean producers in northern Mato Grosso, nor to Cargill, that rerouting crops to Santarém, approximately 1,300km to the north, represented a travel savings of 800 kilometers over the existing land based, export routes to the southern ports of Paranagua, in the State of Paraná or Santos, in São Paulo State (Cargill 2006, Cargill 2010).

In what may have been a near fatal public relations error, however, Cargill made the mistake of not only locating the port in a highly visible location within sight of the city's riverside boardwalk, but also in promoting soybean production within the vicinity of Santarém itself (Greenpeace 2005a, Cargill 2006). Clearing forest and converting smallholder farms for large scale soybean production resulted in a backlash against the greater soybean industry in Brazil. Greenpeace, the Nature Conservancy, the World Wildlife Foundation all became active in regulating and publicizing the perceived and potential environmental implications of the agricultural sector in the region (RTRS 2012). In particular, NGOs and researchers voiced concern over the prospect of paving BR-163 and of soybean production expanding into the northern regions of the basin (Fearnside 2007). Should BR-163 be improved and paved in its most treacherous sections in western Pará, they argued, the environmental and social implications would be profound. While the federal government hardly scrapped its plan to pave BR-163, construction proceeded with heightened sensitivity to the concerns of indigenous groups, smallholder farmers, and environmental advocates. New initiatives such as a moratorium on planting soybeans in areas deforested in the Amazon biome since 2006 and efforts to make soybean production “sustainable” were also developed. Perhaps more significantly, the government acted to create new protected regions in western Pará, where large tracts of forest remained (Soares-Filho et al. 2008). Progress on the road continues. By the time of the field work conducted for this analysis, the asphalt was complete from Cuiaba to beyond the border with Pará; from there paving is intermittent until Novo Progresso.

6.2 Migration, Property, and Indirect Land Use Change

If the BR-163 region is diverse in both its mechanism for settlement and its suitability for agriculture and ranching, the rapid pace of land use and land cover change here has remained a constant. However, to what extent the growth in soybean production at the southern end of this study region has acted in and of itself as a driver of pasture led deforestation farther north remains unclear. To better evaluate this process, I employed a field survey to understand the mobility of human and financial capital and the motivations that underlie a decision to mobilize. The remainder of this chapter considers these movements and motivations explicitly, and brings to light the results from this field work.

6.2.1. Displacement and migration in the BR-163 region

In Chapter IV I suggested that, just as land is heterogeneous in its attributes and production capacity, so too is the individual that possesses or controls the land, or who otherwise has the capacity to employ it as an input. The production value rendered by a given parcel is thus contingent not only upon the attributes of the land itself, but upon the bundle of land attributes and the skills and capacities of the individual responsible for it. As economic conditions change over space, and as the relative value of land increases or decreases, to maximize the value of their skills (and also of the land), farmers and ranchers will face incentives to not only change the way that they use their land, but also to relocate their skills. The relocation process is of principal interest in this analysis, and calls to concerns of indirect land use change, namely through the displacement and relocation of skilled labor and use-fixed capital from established areas to more marginal zones of production. This displacement and relocation process is itself a function of opportunities or opportunity costs, driven through the appreciation of land and relative price differentials for cropland, pasture, and forest cover across and between agricultural regions in Brazil.

For displacement to occur, the former landowners must have the means by which to liquefy or release their skills and capital from their land. This process begins with the sale or renting of land, where the purchasing party remunerates the seller or renter for the value of their property, which can then be invested in another location or activity. It must also be recognized that access to capital has long been viewed as an impediment to land use change in the Amazon (Walker and Homma 1996, Pichon 1997, Walker et al. 2002, Caldas et al. 2007) and that, as displaced ranchers and farmers relocate to marginal ranching and agricultural regions, they also relocate their capital. The process not only acts to free and spatially redistribute capital and skills to new regions of the Amazon, but it renders areas once limited by scarce capital and labor into areas capable of production.

In this sense, a change in rents and the purchase or transfer in control of land to a farmer or rancher from another farmer, rancher or timber company constitutes three important actions (figure 6.2). **First**, upon relocating or retiring, they are able to liquidate the value of their property, which, in the case of relocation, directs it to another location (or, potentially, another sector). If they choose to continue in the same profession, they will need to find a new location in which to reestablish their operation. If they decide to bring their capital to more marginal lands, they now have the financial wherewithal to open, clear, or prepare natural or degraded lands for more intensive production in these areas. **Second**, the sale of land implies the transfer of control from one agent to another. Presuming that the selling agent possesses a set of skills that is likely to be still relevant to production, the party may choose to migrate to a new location, bringing with them the knowledge essential to reconstituting their former production strategy at the frontier. **Third**, the new owner may provide new access to capital, and thus the potential to invest in clearing, cleaning, or preparing land for more intensive production. This framework, while acknowledging adjustments in supply and demand as the principal avenue by which indirect land use change occurs, recognizes equilibrium adjustments of another type, namely ones of knowledge and capital essential to agricultural and beef production. Amidst rising values for land and increased access, capital tied to the agricultural and beef sectors disseminates over a landscape, prompting new investments, land cover change, and producer displacement.

In this sense, I tie spatial access to capital at the margins of the frontier to the creation and displacement of resources and capital in consolidated agricultural districts.

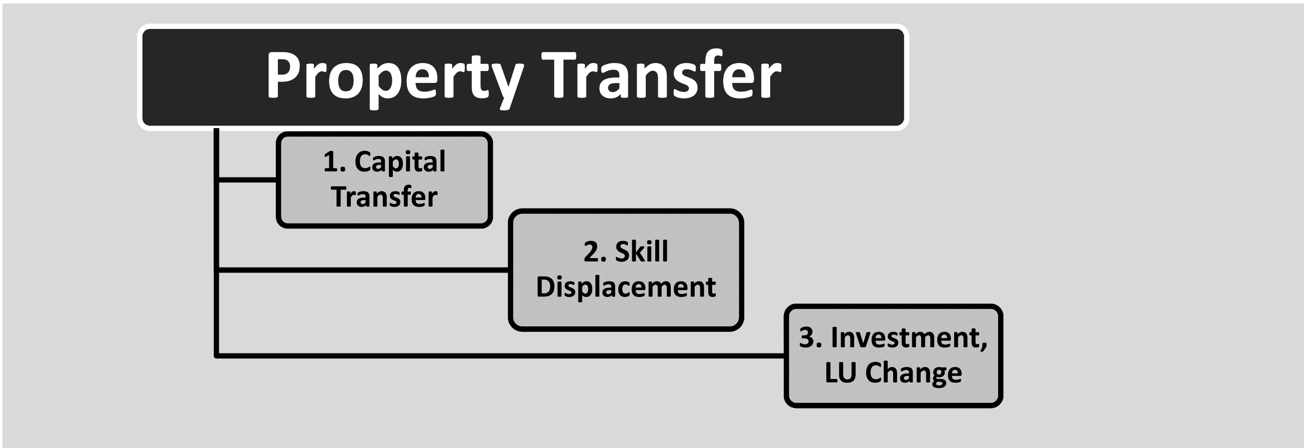

Figure 6.2. Property Transfers, Displacement, and Investments

6.3. Survey Design and Implementation

I build this research on the presupposition that a land sale represents a transfer of capital, either between or within production sectors, and between agents embodied with a specific set of skills. If the seller or purchaser is relocating after the sale, the sale also represents a spatial redistribution of capital. In the current context, I see indirect land use change as being driven by this process, from the farm level to regional, national, and even international scales.

To better understand the spatial connections underlying field level land use change, I designed a field survey for deployment in the BR-163 region. This survey targeted purchasers of property since 2000, or since the commencement of the soybean boom and the emergence of the Amazon region as a significant player on the global marketplaces for both beef and soybeans. My decision to focus solely of sold properties was deliberate and made with the premise that the indirect impacts of land use change are tied to the displacement of skills and capital.

The survey questioned recent property purchasers regarding both their own origins and the seller's destination. In effect, I designed the questionnaire to capture the flow of people and resources into and throughout the Amazon, as well as any land use changes that have taken place as an artifact of property acquisitions. Specifically, the survey instrument gathered information on (a) the skills and background of the purchaser, (b) the motivations behind the purchase, (c) any land use or land cover changes affected after acquisition, (d) the seller's decision to relocate, and (e) the destination and occupation of the seller after the sale. The survey, while broad in the scope of information that it seeks, was succinct in its investigation. I list several of the survey questions in the flow diagram on the following page (figure 6.3).

Hypothesis **H2.1**, or that land use change elsewhere in Brazil is linked to deforestation in the Amazon region, is partially addressed by questions 1 and 2. I address **H2.2**, on the motivations driving relocation and the concept of relocation and migration as a means of increasing access to land, with questions 5 and 6. **H2.3**, which suggested that relocation decisions are a function of distance and land prices, links to question 7. I link the fourth hypothesis, **H2.4,** where land use change occurs with changes in control over land, to question 8. The last two hypotheses, **H2.5** and **H2.6**, which directly consider indirect land use change, I address through questions 8 through 10.

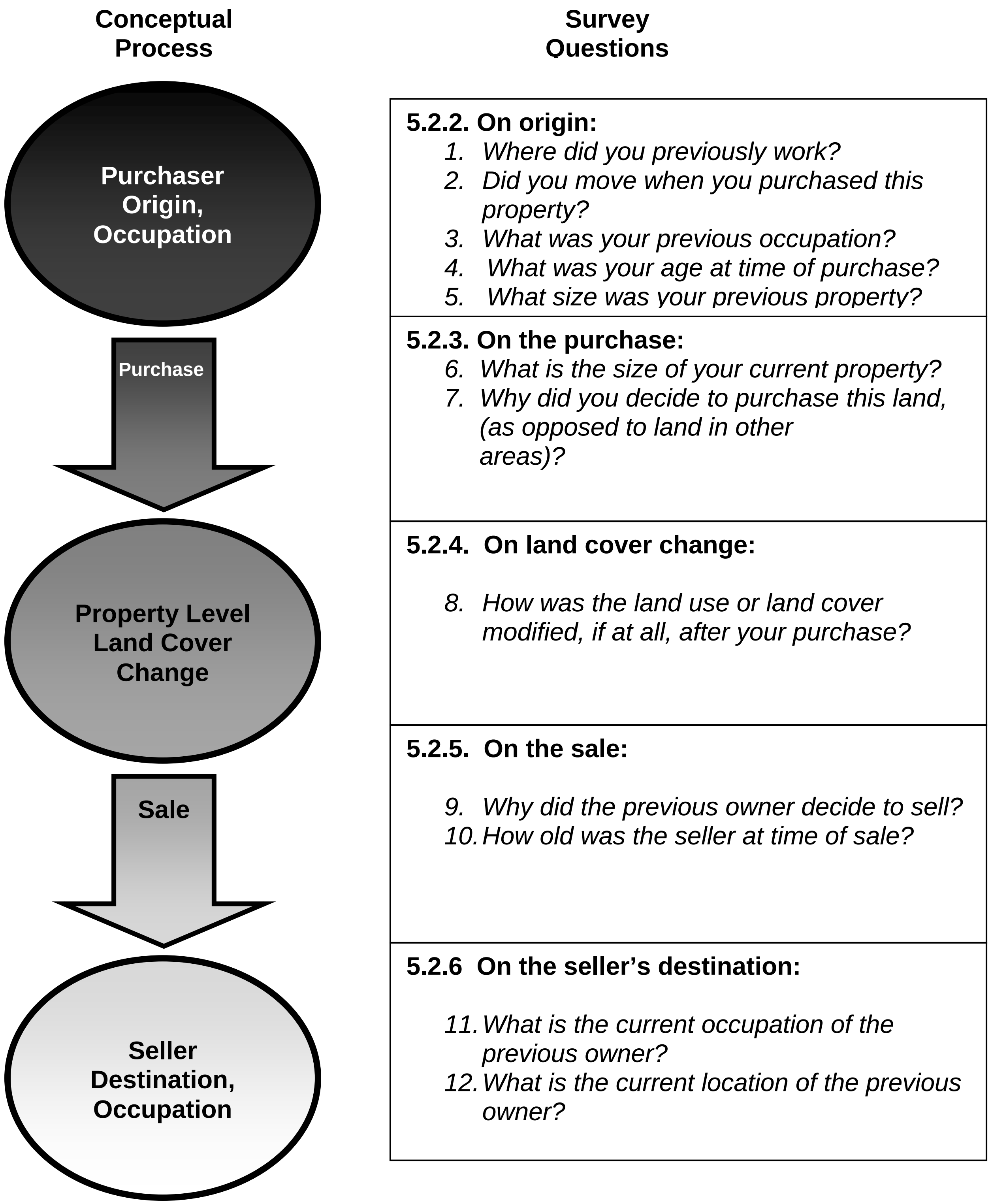

Figure 6.3 Survey Flow and Migration Process

Collecting surveys from a specific set of subject targets (i.e., purchasers of land since 2000) across a seven hundred kilometer survey region was a complex task. To accomplish the feat, I adopted a multi-pronged effort to locate potential subjects. These efforts generally began with initial visits to the local producers' unions, the municipal secretary of agriculture, and *cartorios*, or the private offices responsible for registering land titles in each Brazilian *comarca* (an administrative unit that may include multiple municipios). After explaining the intention of my work to the union president, agricultural secretary, or *cartorio* owner I would ask them to suggest the names and contact information of recent land purchasers.

The discussions and answers received from each contact varied widely. The *cartorios* could provide information only on properties larger than 250ha and sold since 2007. In Mato Grosso, the local branches of FAMATO (Federação da Agricultura e Pecuária do Estado de Mato Grosso[23]) also provided key contacts. After discussing my project with the local branch president I would ask him or her to suggest several names of recent land purchasers and, if possible, contact information. I took a similar path with key contacts elsewhere in the agricultural sector. The responses varied from branch to branch or from office to office, with some branches calling and setting up meetings on my behalf, others supplying names and phone numbers, and others indicating that they did not feel comfortable identifying recent purchasers of land. The branches at Sinop and Sorriso were particularly helpful in this regard, as both not only assisted me in finding recent land purchasers, but also provided meeting space for interviews in their respective conference rooms. The Sorriso and Sinop branches are particularly influential in the region, and many farmers and ranchers operating in neighboring counties actually live in these cities, and are members of these organizations. In addition to working through local

[23] Federation of Agriculture and Ranching of Mato Grosso

institutions and organizations to identify recent land buyers, I also found recent land purchasers through less structured means. From casual conversations, discussions with hotel employees or owners, friends or neighbors of contacts, I was able to pinpoint additional potential subjects. Some of the potential survey subjects were skeptical of speaking with a foreign researcher, and several declined to participate.

For those that did participate in the survey, meetings would take place either at the owner's office (many of the soybean farmers and larger ranches have offices in the city), at the local branch of the producers union or agricultural secretary, or at a neutral location, such as a hotel lobby or gas station cafe. Interviews lasted between 10 minutes and 1.5hrs, depending on how much the subject had to say.[24] Given the difficulties in locating interview subjects that had specifically purchased land in the past ten years, as well as the immense distances and harsh travel conditions, the 54 surveys collected represented an immense task. Over the course of the eight weeks that I was aggressively pursuing survey subjects, I logged approximately 10,000km in my rental car.

It is important to note that the sample selection, though made as random as possible, is not a purely random selection. I adopted what I came to refer to as a shotgun-snowball sample technique, or where I sought possible subjects through both formal institutional channels (local government, producers' unions, agricultural supply stores) and through random encounters, with the latter including acquaintances of friends, random meetings at hotels, on the road, at stores, etc. After an interview I would often ask if the subject had any acquaintances of friends in the area who had also bought land. Where possible, I would also pursue an interview with these contacts as well. I admit that the selection method is naturally biased toward land purchasers

[24] An English version of the questionnaire is included in the appendix.

whom had been in the area for a longer period, as these individuals were more likely to be involved in local producers' unions or be more known in the region.

6.3.1. Origins and Destinations: those that purchase.

The displacement process associated with the investment effect requires a transfer of production space from one land manager to another, and therefore a displacing agent, or a purchaser of property, to acquire land. Implicit in this process is the transfer of capital from the displacer to the seller, who presumably must reside in another location, but who may or may not relocate to take advantage of their new acquisition.[25] I thus view each purchase as representative of a spatial relocation of capital, both in financial and social form, with the latter embodied in the production knowledge and networks of the purchaser (Richards 2012). An examination of purchasers' prior residences and occupations, as well as the location of their purchase, is seen as offering insight into the origins of capital and knowledge flowing into the Amazon, which is fundamental to the objective at hand.

At the outset of this analysis, it is important to state that many of those purchasing land in the BR-163 region since 2000 had moved to the region from homes located far away. Of the 54 interviewees surveyed, 21 had arrived from outside of the Brazil's North or Center-West regions; and of these, nearly all arrived from the southern states, with the remainder coming from the Brazilian-settled areas in Paraguay. Of those who purchased properties in this region, each already possessed prior experience with their present production strategy. In other words, every rancher purchasing land in the region had had prior experience managing cattle, just as every farmer purchasing land with the intention to farm had already possessed experience working in

[25] In some cases, established farmers in consolidated regions may purchase additional properties in peripheral zones, but remain in their prior residence.

agriculture. This apparent "fixing" of skilled labor to the ranching and agriculture sector is in fundamental agreement with the location-utility model presented in the previous chapter.

However, another, perhaps less expected, process becomes visible through the survey data, namely that of a trend in recent years towards concentration. Per the survey results it was evident that, whereas many of the property purchases during the boom years of 2000-2004 were made by farmers and ranchers coming into the area from outside the region, in recent years most of the purchases were completed by farmers and businessmen already operating in the region. Distilling the 54 purchases into *concentrations* and *migrations* and examining this pattern over time confirms such a shift. Concentration, in the present context, refers to land acquisitions by a nearby landowner with no relocation evident after the purchase. Migration, in contrast, refers to purchases made by a buyer coming from some distance away. Typically, a new residence is implied in a migration purchase (though this was not specifically asked in the short questionnaire).

With these migration and concentration categorizations in place, the chronology of purchases suggests that initially (prior to 2005), most of the land purchases surveyed were made by in-migrants (Figure 6.4). After 2005, however, the trend reverses, with most of the purchases made by local landowners adding to their land holdings rather than in-migrants. The fifty-four surveys, of course, likely do not constitute a sufficient sample of the total land purchases in the region made during the time period, and thus while indicative, are not sufficiently representative to formulate a definitive empirical statement. However, they are suggestive of a trend towards concentration and a shift in the relocation of capital in the region. This trend may be indicative of a larger story where, during the early years of the soybean boom rapid growth in the region demanded outside investment capital and additional skilled labor, particularly in agriculture. The more than 100% appreciation of crop and pasturelands in Mato Grosso between 2000 and 2003 lessened the perception of risk, as rising land values provided insurance against production losses (FNP 2002-2011). The spatial disparity in prices, I might suggest, provided an economic landscape where ranchers and farmers in the comparatively economically well off regions of southern Brazil might relocate northward to seek larger properties for agriculture; as they came, they brought with them their experiences, and thus provided an infusion of both capital and skilled labor into the region.

This migration pattern appears to have slowed after 2004, when low prices for rice, soybeans, and beef diminished potential profits and in some cases ruined those who counted on sustained high prices to sustain their investments. When prices returned (e.g., 2008 to present) growth resumed and land sales rose again, as indicated in the timeline of land purchases. However, when growth did return there was a clear shift toward concentration. Wealth produced in the region was now sufficient to sustain its own growth, and the advantages that farmers from the south once had in eyeing land in the Amazon, namely much higher valued properties and nuanced knowledge of the soybean sector, were no longer as significant as previously. This pattern is suggestive of the growing inequality that appears to accompany the rapid growth in soybean production (Weinhold et al. 2011).

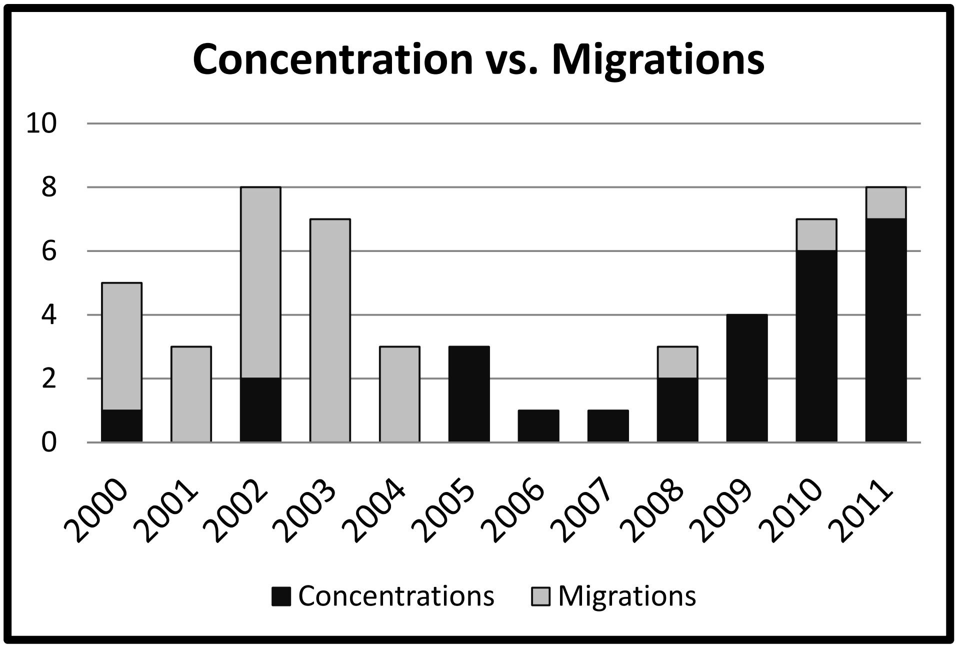

Figure 6.4. Property Sales by Year, Differentiated According to Concentration and Migration.

With the distinction between concentration and migration purchases laid clear, this section will proceed to a closer examination of the pathways of migration, or of specific places of origin for in-migrating ranchers and farmers. As indicated at the outset of this section, many of those who migrated into the BR-163 region arrived from outside of the Center-West region. Generally, the results suggest that farmers migrating into the BR-163 region had left consolidated agricultural frontiers; for ranchers, movement was from areas of consolidated cattle frontiers, or from traditional ranching strongholds in Brazil's interior. For in-migrating farmers, the majority were "gauchós," a colloquial term for natives of Brazil's southernmost State of Rio Grande do Sul; for ranchers, the situation was more spatially complex, which might be expected, given the broader spatial dispersion of ranching across the Brazil and the Amazon. Arrivals to northern Mato Grosso and western Pará included emigrants from the South of Pará, from Goias and Tocantins, and from South Mato Grosso State. I show the points of origin of migrating land purchasers in figures 6.5-6.8, which illustrate the northward movement of both farmers and ranchers. The maps also show the trend of moving from areas of high land values to areas of lower land values. I interpret these trends as suggestive of a linkage between the creation of new productive lands and the in-migration of farmers and ranchers from elsewhere in Brazil. They are also suggestive of a tie from deforestation and land use change to changing population and economic dynamics elsewhere in Brazil. Such migration patterns provide support for hypotheses **H2.1**.

Evidently, migration largely appears to have originated from regions which were rich(er) in skilled labor, but where land had been consolidated into systems of medium and large parcels, where larger tracts of cropland are more difficult to acquire. This process has already been well documented in Brazil's southern states where, for those wishing to expand their landholdings, expansion in that region was rarely an option (Margolis 1973, Foweraker 1981, Almeida and Campari 1995). For farmers and ranchers seeking to improve upon their current economic situation or, employing the language of the location-utility model from Chapter IV, to maximize the expected utility of their skills, migration to the Amazon presented one of the few options by which to capture more productive land. Evidently, the process has continued over the past decade, though both the risks and the reward associated with relocation have greatly diminished. With this in mind, I turn toward considerations of the process underlying farmers' and ranchers decisions to purchase additional land.

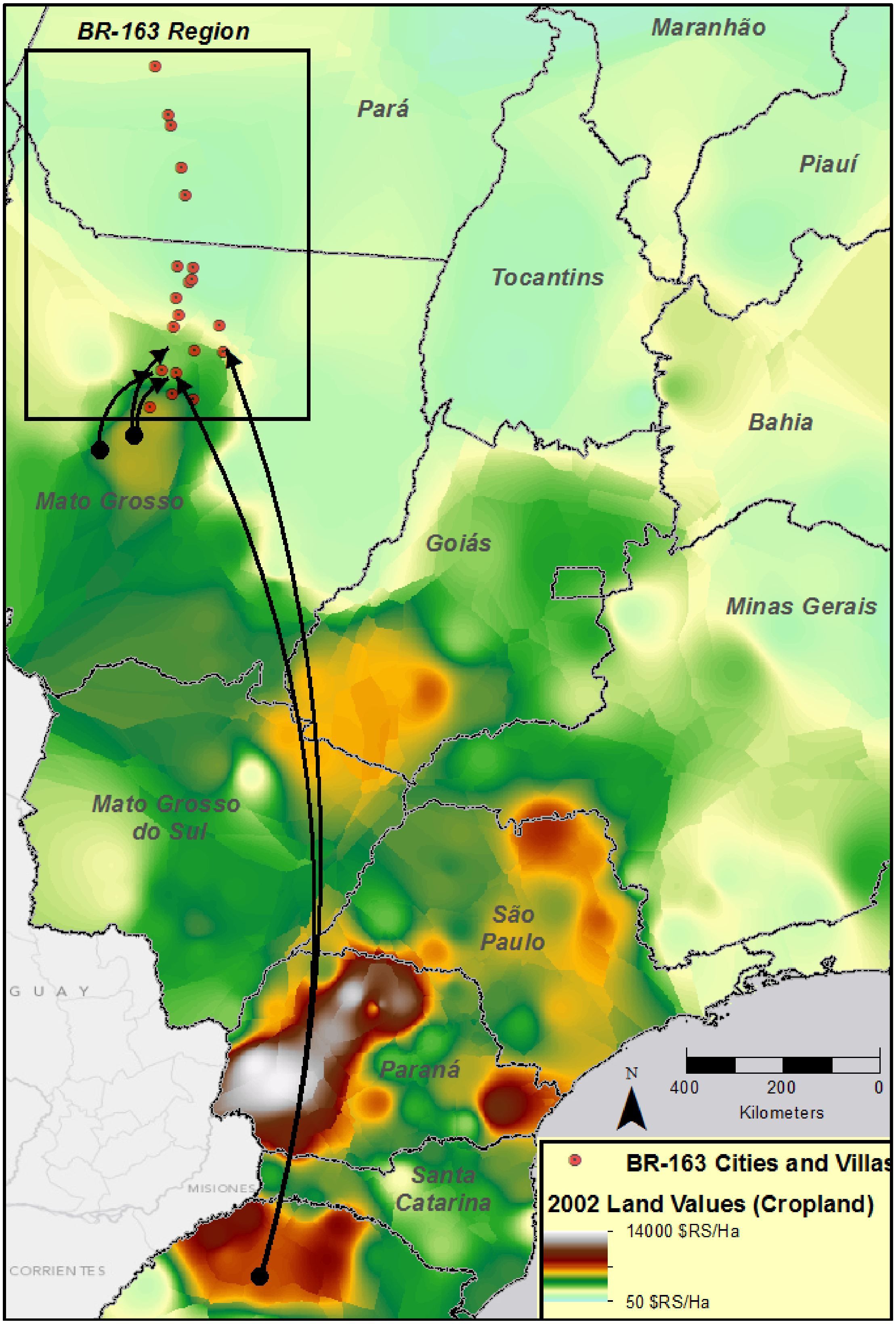

Figure 6.5. Farmer migration to BR-163 region between 2000 and 2002. *Cropland values are shown for the year 2002.*

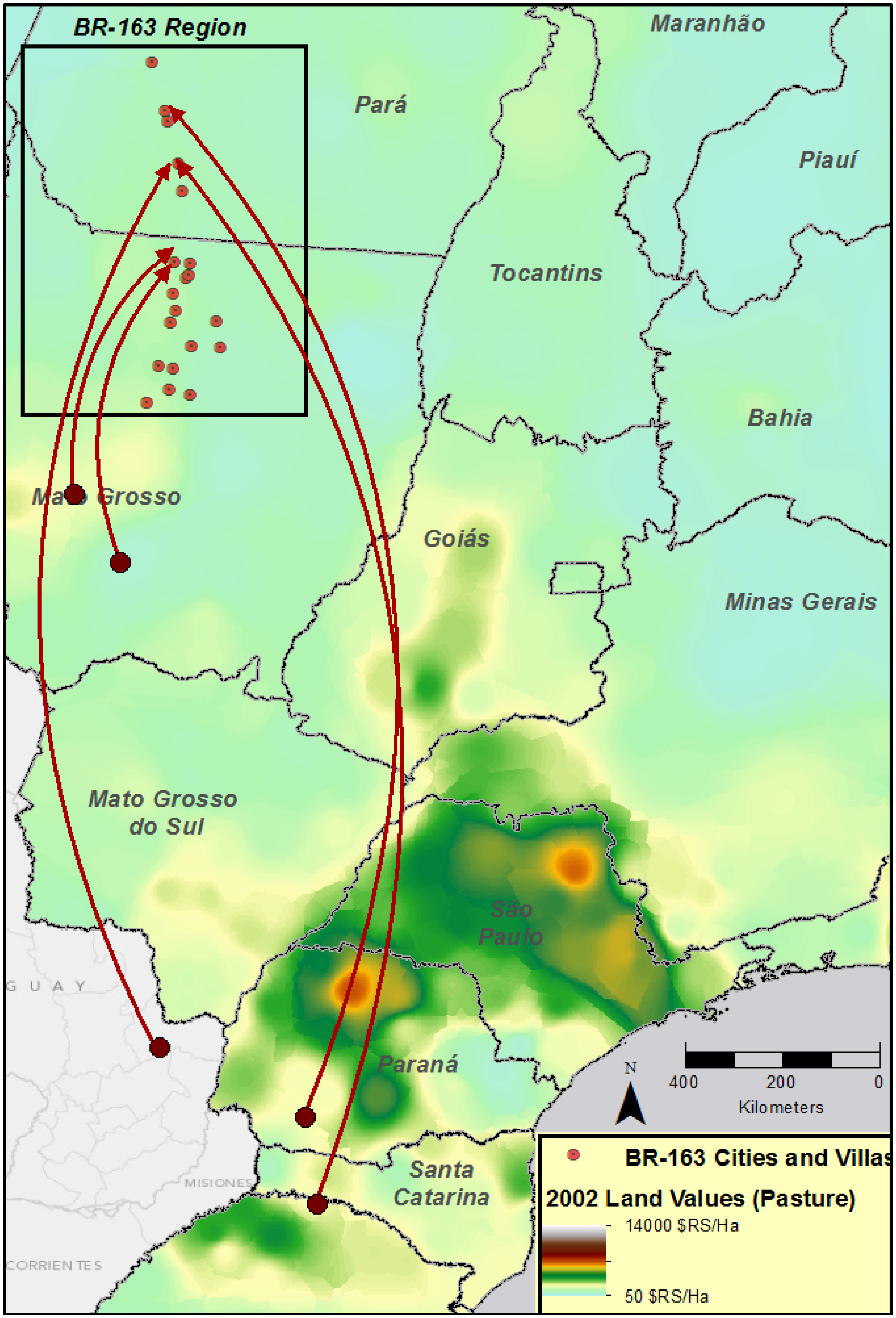

Figure 6.6. Rancher migration to BR-163 region between 2000 and 2002. *Pasture values are shown for the year 2002.*

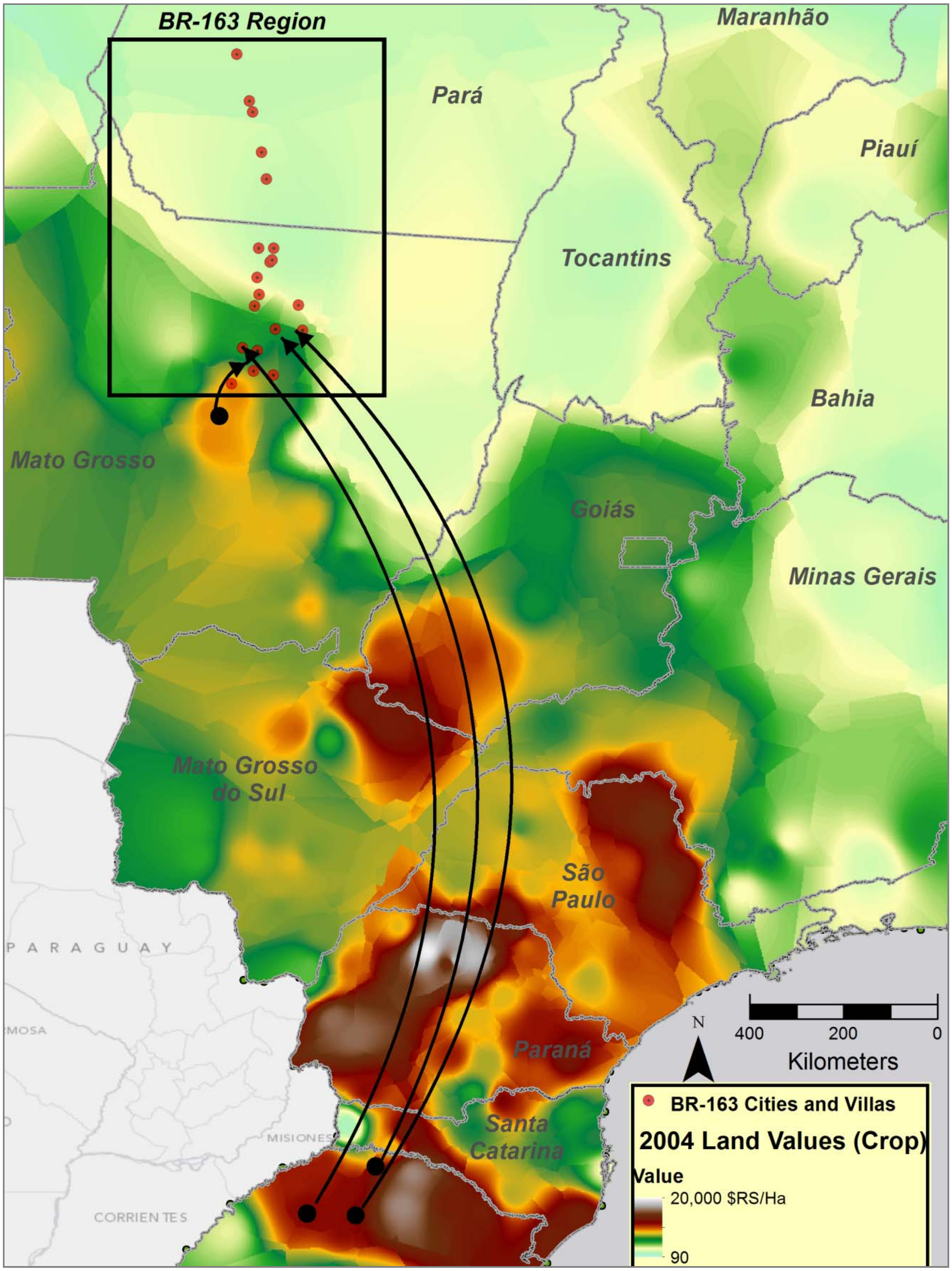

Figure 6.7. Farmer migration to BR-163 region between 2003 and 2010. *Cropland values are shown for the year 2004.*

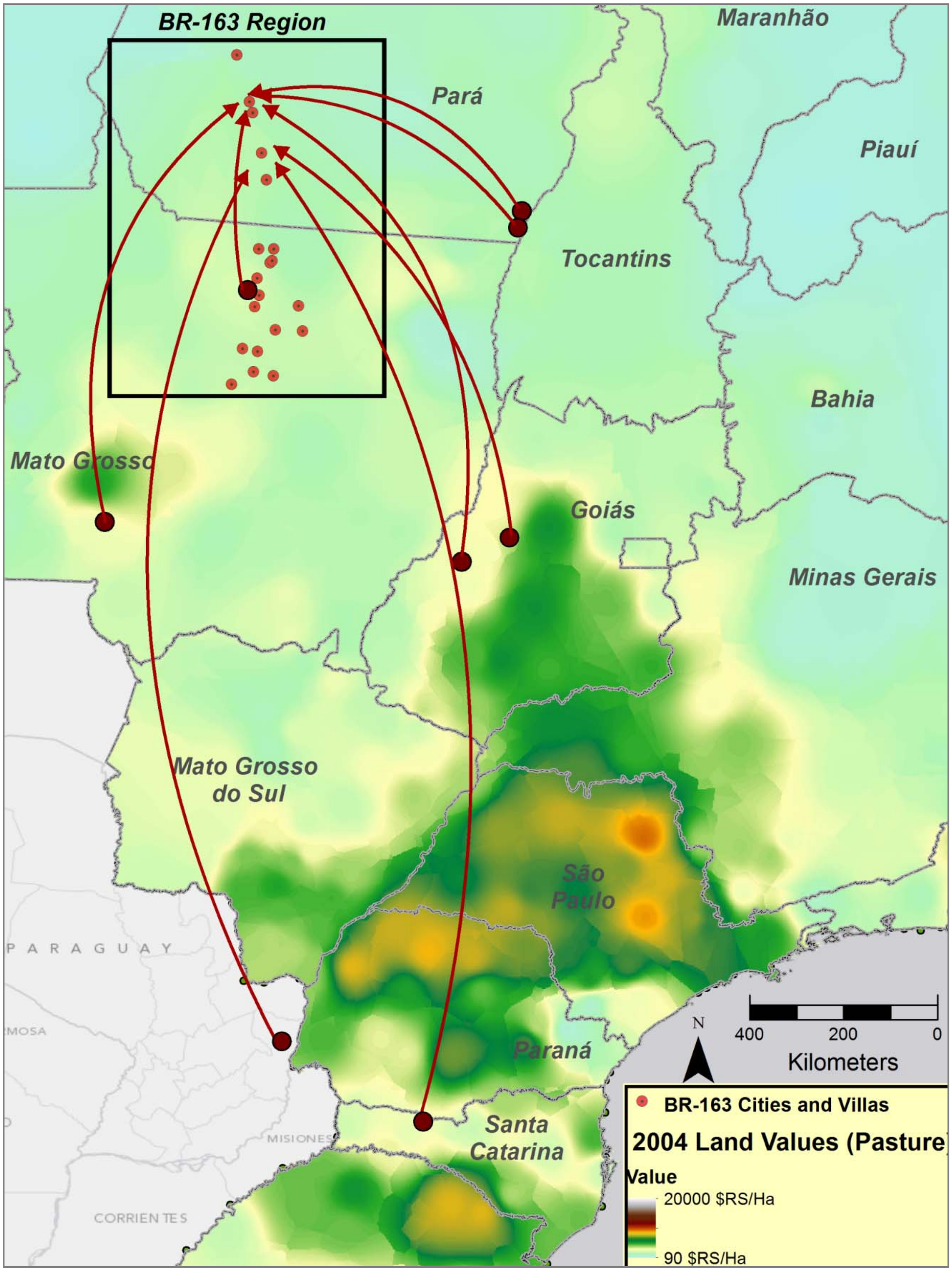

Figure 6.8. The migration of surveyed ranchers arriving to the BR-163 region between 2003 and 2010. *Pasture values are shown for the year 2004.*

6.3.2. Making the purchase: the buyers' decision making process

Each property owner was questioned regarding their decision to purchase new properties. In their responses, several answers were recurrent: (a) price/value, (b) prior knowledge of the property; (c) the quality of the land; (d) access to the property or proximity to a road; and (e) whether or not the land was "opened," or already deforested. Overall, thirty-nine of the fifty-four property purchases were motivated at least partly by the price of the parcel, the distribution of which warrants further discussion.

In Brazil, historically, skills and capital have been concentrated in the nation's southern states and in the hinterlands of São Paulo. A similar distribution is also evident in the distribution of the nation's land prices (see tables 6.3-6.4 and figures 6.5-6.8).[26] The spatial distribution of land prices across Brazil reflects the disparity in agricultural rents, with the southern and coastal regions benefitting by their relative ease of access to the nation's ports and metropolitan areas, while the in the Amazon, where producers spend as much as fifty percent of their product prices on shipping their goods to market, per hectare profits for cropland are lower and land prices decline precipitously.

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[26] A full description of the data used to compile the land price maps is included in section 6.5.3 in the following chapter

Table 6. 3. Real Mean Cropland Values ($Rs/Ha) in Principal Agricultural States Values are real values calculated from FNP land price data (2002-2011)									
State | Year:	2002	2003	2004	2005	2006	2007	2008	2009	2010
Parana	**7429**	**9,450**	**9,745**	**7,449**	**7,066**	**7,883**	**9,703**	**10,164**	**9,349**
São Paulo	**4960**	**6,471**	**7,911**	**7,258**	**6,998**	**8,668**	**9,225**	**8,913**	**8,408**
Santa Catarina	**3854**	**5,004**	**6,937**	**6,105**	**5,829**	**6,358**	**7,987**	**8,591**	**8,865**
Mato Grosso do Sul	3780	5,705	6,320	4,400	4,119	4,605	5,334	5,082	4,841
Rio Grande do Sul	**3656**	**5,266**	**6,734**	**5,213**	**4,744**	**5,105**	**6,396**	**6,580**	**6,191**
Goias	3603	5,048	5,603	3,553	3,003	3,865	4,424	4,938	5,221
Mato Grosso	**2571**	**3,866**	**4,345**	**3,159**	**2,871**	**3,009**	**3,494**	**3,489**	**3,339**
Rondônia	1943	3,420	4,535	3,537	3,248	3,027	3,378	3,387	3,195
Acre	1721	3,028	3,878	2,989	2,743	2,583	2,879	2,862	2,660
Piaui	1270	1,918	2,435	2,033	1,973	2,075	2,742	2,801	2,412
Tocantins	1159	1,703	2,136	1,723	1,643	1,906	2,568	2,888	3,068
Pará	**974**	**1,441**	**1,567**	**1,256**	**1,202**	**1,479**	**1,709**	**1,483**	**1,339**
Maranhão	940	1,354	1,753	1,430	1,364	1,746	2,509	2,627	2,527
Amazonas	746	1,255	1,519	1,225	1,148	1,121	1,097	1,014	964
Roraima	210	698	962	918	869	854	753	696	703

***Table 6. 4.* Real Mean Pasture Values ($Rs/Ha) in Principal Agricultural States Values are real values calculated from FNP land price data (2002-2011)**									
State	2002	2003	2004	2005	2006	2007	2008	2009	2010
São Paulo	3,714	4,526	5,304	5,039	4,720	5,538	5,769	5,777	5,681
Parana	**2,842**	**3,806**	**4,318**	**3,496**	**3,208**	**3,248**	**3,797**	**4,314**	**4,167**
Santa Catarina	**1,881**	**2,317**	**2,870**	**2,712**	**2,563**	**2,571**	**3,470**	**3,911**	**3,947**
Rio Grande do Sul	**1,601**	**2,264**	**2,952**	**2,572**	**2,540**	**2,441**	**2,524**	**2,753**	**2,782**
Goias	1,561	2,070	2,716	2,217	2,083	2,405	2,652	2,854	2,974
Mato Grosso do Sul	1,406	2,094	2,349	2,068	1,943	2,356	2,724	2,624	2,770
Mato Grosso	**934**	**1,366**	**1,605**	**1,375**	**1,274**	**1,357**	**1,492**	**1,500**	**1,464**
Tocantins	852	1,092	1,224	1,160	1,092	1,065	1,107	1,259	1,524
Rondônia	760	1,112	1,485	1,361	1,269	1,402	1,518	1,450	1,450
Pará	**692**	**819**	**871**	**783**	**741**	**716**	**1,001**	**934**	**890**
Maranhão	517	629	677	738	713	700	717	763	892
Piaui	353	354	345	324	309	328	358	358	345
Acre	312	392	498	553	527	707	1,104	1,080	1,020
Amazonas	248	331	423	432	406	470	585	568	549
Roraima	242	358	476	460	440	447	424	419	428
Rate of Adj.	**1**	**1.093**	**1.176**	**1.242**	**1.282**	**1.339**	**1.418**	**1.479**	**1.566**

From the farmers and ranchers surveyed as part of this research, the tradeoff between amenities and access with quantity of land was readily apparent. Those that had chosen to relocate from one region to another had found that the disparity in land prices validated their migration. This choice stemmed from the realization that through relocation they could (in effect) exchange their smaller parcels in the south or closer to highways (if already in the Amazon) for larger parcels farther north or in more remote areas. Whereas access to land in the south, they felt, was unlikely to ever improve, given the property structure and high costs of agricultural land there, the amenities and infrastructure of Mato Grosso had already improved tremendously, and were likely to continue to do so in the future. Investing in Mato Grosso was seen by those who had moved into the region as a solid investment, and one which would pay dividends in both the short and long term. It also represented one of the few means by which medium or smallholder farmers in Mato Grosso could expand their access to land.

Given that the migrations documented in this survey were primarily incentivized by regional disparities in price and the ability to acquire large tracts of land, it is not surprising that in every migration case the purchaser acquired property exceeding their previous holdings (in size). Of the respondents, most managed to at least double the size of their properties (table 6.5) and in some cases migration resulted in far larger acquisitions, particularly for those who relocated to the State of Pará where access remained difficult, but where land prices were far lower than in Mato Grosso. In all but one case every migrant into the region mentioned having had received what they felt to be a favorable price (at least in comparison to their previous location).

Purchasers mentioned other factors aside from price, however, and a tradeoff emerged from survey discussion between price and prior knowledge of a particular piece of property. Knowledge of an area and easy access from existing operations was also of interest to local land purchasers who were unlikely to relocate to take care of their new properties, particularly in cases where the purchase was from a neighbor or nearby farm. Knowledge of the land to be purchased, including an idea of how the land had been used and its potential yields, acted to offset some of the risk associated with the purchase, thus compensating the potentially higher price to be paid.

In many cases this tradeoff was explicitly stated, and some of the respondents went so far as to clearly state that their decision to relocate (if within the region) was a balance between their knowledge of the area and the price asked. In some cases, the surveyed landowners reasoned that while they might find more affordable land in the States of Maranhão or Tocantins than in the BR-163 region, the amenities of those regions were less, and they were less familiar with the production dynamics in those locations. Rather than look for land in these distant states, they decided to relocate their production to areas of Mato Grosso where prices were slightly higher, but where they would continue to have some degree of access to the core agricultural service facilities located in the vicinity of Sorriso and Sinop. The tradeoff between knowledge and price is particularly stark when considering the motivations of in-migrants (as classified in the previous section). For migrating purchasers, 22 of the 23 stated that a principal motivation behind their purchase was the price of the land. Only three of these respondents indicated that they had significant knowledge of the land prior to purchase (figures 6.9-6.10).

A preponderance of responses by migrating producers indicated that difference in price was a principal factor motivating their purchasing of land in northern Mato Grosso while local, established farmers were more likely to mention previous knowledge of the property. This is strongly supportive of hypothesis **H2.3**. The decision to migrate to a region carries enormous financial risk; it is only when the difference in access to inputs becomes of such a magnitude (and the opportunity to purchase arises) that a move, and the spatial redistribution of capital that it entails, comes to fruition. Surveys and discussions with key informants also indicated a focus on expanding access to land, as hypothesized in **H2.2**. Each migrant into the region succeeded in acquiring larger properties through relocation.

Table 6.5. Land Access for In-Migrating Farmers and Ranchers.
Purchases in the State of Pará are listed in bold.

Purchase Year	Area of Previous Property (ha)	Area (ha) Purchased	Difference btw previous and present property	Percent increase
1995	**600**	**4100**	**3500**	**324**
2000	350	500	150	43
2001	0	280	280	n/a
2001	420	6000	5580	1329
2002	720	2400	1680	233
2002	**36.3**	**1500**	**1464**	**4032**
2002	314	624	310	99
2002	200	900	700	35
2003	1000	1900	900	90
2003	180	900	720	400
2003	**157**	**1635**	**1478**	**941**
2003	**73**	**550**	**477**	**653**
2003	**580**	**1936**	**1356**	**234**
2003	**26**	**193**	**167**	**642**
2003	**400**	**5000**	**4600**	**1150**
2004	**0**	**779**	**779**	**n/a**
2006	**100**	**400**	**300**	**300**
2007	85	360	275	324
2010	38	121	83	218

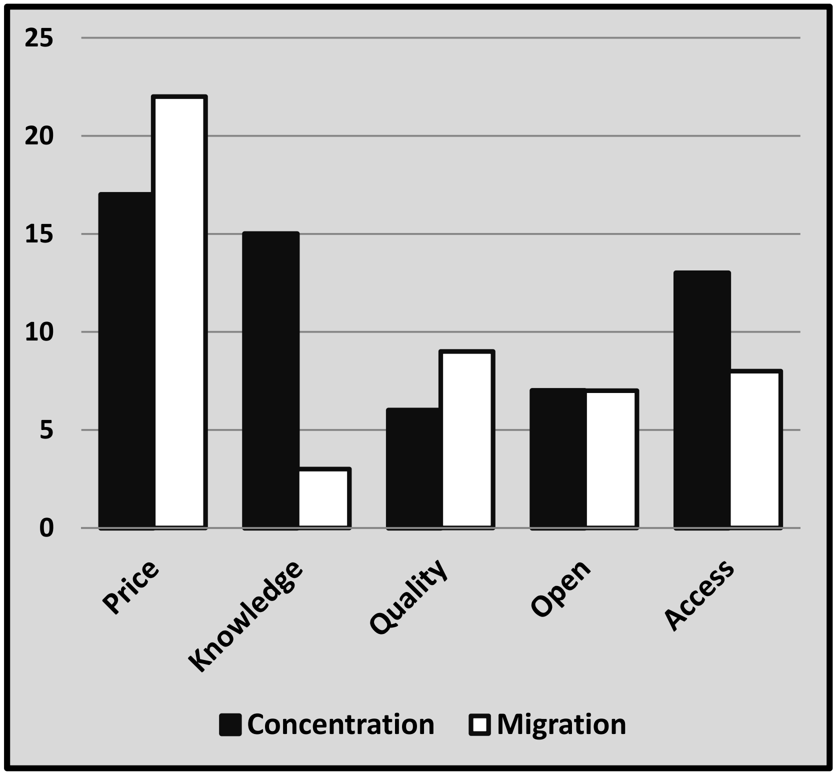

Figure 6.9
Factors Underlying Purchase Decisions (Number)

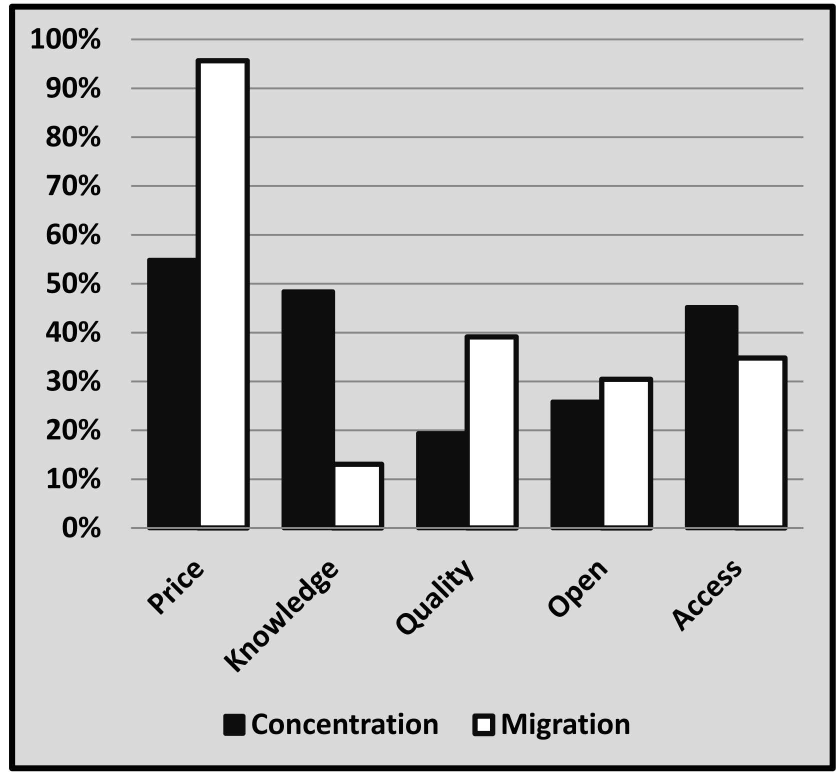

Figure 6.10.
Factors Underlying Purchase Decisions (Percentage)

Number and Percentage of respondents indicating most important factors behind their decision to purchase their new agricultural properties. *Results separated as concentrations (n=23) and migrations (n=31).*

Beyond price and knowledge, other elements or attributes mentioned by the survey respondents included access (referring to proximity to road), the quality of the parcel, and the state of its forest cover. Proximity to roads, a Thünian attribute with implications for both farm gate price and ease of access, was especially important to buyers already present in the region. In-migrating purchasers apparently placed less emphasis on road access, which I interpret as a greater willingness to travel to more remote areas and as an artifact of their broader interest in maximizing land holdings (rather than access to urban amenities). To some surprise, neither migrants nor established land purchasers in the region frequently mentioned land quality, soil quality, or overall aptitude for agriculture. Several respondents did mention topography, principally in Pará, where the terrain is more varied.

The final category, namely openness, or whether or not land had already been deforested, was particularly important to those purchasing land during the most recent years. Historically, the cost of opening new land has pushed farmers, who would face high costs to not only clear land, but to clean it of stumpage and other detritus, to acquire already cleared parcels (USDA 2007).[27] More recently, however, another, non-economic obstacle to clearing new land has emerged, namely the time-consuming bureaucratic impediments and increased controls on deforestation, which have rendered it more difficult to clear land legally than in years past. Respondents regularly cited the increased vigilance by IBAMA and potential obstacles for farmers without environmental papers seeking financing for their crops as potential issues with

[27] To some extent this was not the case, however, in the vicinity of Sinop and Sorriso, where timber companies had historically controlled much of the surrounding areas. Here, during the height of the soybean boom large tracts of land were converted directly from forests and cerrado vegetation to agricultural production. Farmers in these regions possessed several important advantages. First, property rights were relatively clear in this region, where much of the area was owned by timber companies. Second, proximity to the existing soybean producers eased access to the essential support industries necessary to production.

opening new land. At the same time, owners of forest areas now face the responsibility of acting as a steward to their forests and bear the uncompensated responsibility for its welfare. The best way to avoid potentially damaging bureaucratic issues and to evade the responsibility of maintaining forest areas, said many of the respondents, was to simply avoid purchasing areas not yet cleared.

6.3.3. Property impacts: land use and land cover change after purchase

I also questioned each property purchaser regarding land use changes on their property since purchase. Of the fifty-four properties surveyed, thirty-four had changed the use of their land after purchase or (in the case of very recent purchases) had plans to do so in the near future. The categorization of land use change used here requires some additional clarification. Because the properties in question are large, and land use change, being an expensive and time consuming process, is rarely complete in its extent over a short time horizon, land use change was never a zero sum effect. Legal issues likewise complicate the matter, as farmers are by law prohibited from clearing the sum of their properties. While recognizing the problematic nature of classifying land use change, this survey took a simplified, approach. Where land use change of any magnitude occurred after the purchaser took possession I classified the parcel as having gone through a land use change. This included both land converted from forest to pasture and land converted from one land use to another, typically from pasture to croplands. I included in the process the "cleaning" of *juquirão*, or the lower level vegetation of logged and degraded forests or secondary growth. This was done, in part, because ranchers or farmers often suggested that they had not deforested on their own; rather they would say that the "dirty work" had been done by loggers or a prior land owner who had removed the larger trees, often for timber, and who then had perhaps set fires to thin the vegetation, but had not succeeded in fully opening the land.

In these instances, ranchers or farmers often declared that their land had been deforested but "deforested badly," or that the land was never fully cleared. Finishing the job, and fully clearing the land and rendering it into pasture or agriculture was thus, in the present context, considered land use change.

It was also problematic that in several cases land use change was not merely from one land use to another, but rather, occurring across multiple dimensions. For example, farmers, restricted by capital access, might choose to convert only a portion of their property to farmland after purchase. Rather than complete the process in a single year; the new owners would complete the process over several. In other cases, landowners opened or converted portions of their areas to pasture at the same time as they converted pasture areas to agriculture. I classified these parcel changes according to their relative magnitudes. I found no instances of lands purchased in crop or pasture and then subsequently left fallow or to revert to secondary forest. With the acknowledgement of these complexities, I classified each parcel as (a) no land over change occurring, or as (b) forest to pasture, (c) forest to crop, or (d) pasture to crop.

In total, I recorded land use change on thirty-four of the fifty-four properties. Of the 34 instances of land use change declared after purchase, fifteen went from forest to pasture; eleven from forest to cropland, and eight from pasture to cropland. Forest to pasture conversions were predominant at the northern reaches of the study area and to the east of BR-163, on the margins of the Xingu indigenous lands, while forest to crop conversions were more prevalent closer to the established farming zones in the vicinity of Sorriso and Sinop. This is largely in agreement with the location of cattle and soybean expansion. Conversions from pasture to crops were observed along the length of the region, but were most common at its southern reaches, where agriculture has expanded rapidly over the past decade.

The trajectory of land covers observed through the surveys suggested that, not only does land use change take place after purchase, but that the land use process is uniformly one driven by intensification rather than abandonment. Nowhere were croplands returned to pastures, nor were pastures returned to forest. The trend towards intensification is likely a result of increased access to the region, with the continued improvement to the region's road network and the prospect of a completed BR-163 offering a key new export corridor for producers in the region. It is also suggestive of the investment process outlined earlier, where farmers and ranchers reinvest not only their skills and knowledge in new locations, but also the critical new sources of investment capital needed to open and improve land in this region for production. In the present context, land use change thus represents a capital investment; and farmers and ranchers invest in their land by removing its forest cover or the residual stumpage from earlier deforestation. Land clearing is, in this sense, similar to irrigation or fencing; it is an immobile investment designed to improve productivity; an important step, given that forested land is less conducive to beef or agricultural production. A land purchase then also represents a transfer between land owners. It amounts to a spatial relocation in investment capital, with the new owners identifying the less productive, forested or pasture areas as potentially productive for pasture or agriculture and providing the investment capital necessary for their improvement. The findings here are supportive of hypothesis **H2.4**, or that land use changes occur with a change in control over land.

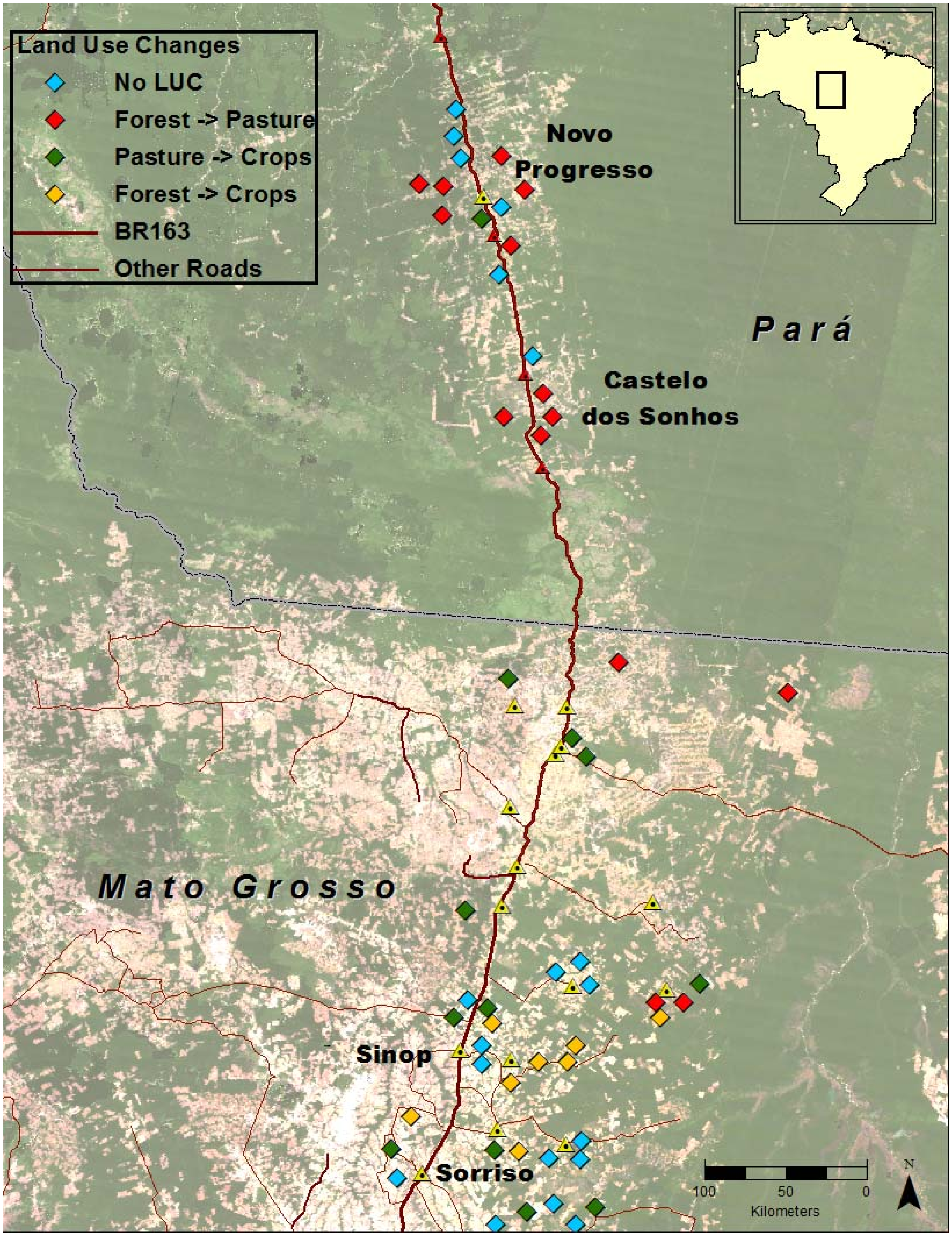

Figure 6.11. Location of surveyed properties, classified by land cover and land use changes. *Locations shown are indicative or proximate, but are not intended to be exact. The yellow triangles indicate the location of the region's principal cities and villages.*

6.3.4. The decision to sell

Just as the decision by the buyer to purchase is indicative of the motivations underlying the displacement process, so too is the decision by the seller to sell their property. Per the location-mobility model, sellers would come to their decision to sell after identifying opportunity costs of remaining and seek to maximize their expected utility by relocating their skills and capital to another location. This is the same process of opportunity identification which draws farmers and ranchers into the BR-163 region, only now examined from the opposite side, namely through those leaving the region, or migrating elsewhere. If the decision to relocate an operation into the BR-163 region is the *direct* driver of land use change, then it is the decision by the land selling, land leasing, or otherwise land ceding agent to reconstitute their operations outside of the BR-163 region that leads, *indirectly*, to land use change.

This subsection and the following consider the residual spatial impacts of land use change and migration within the BR-163 region. There are, however, several shortcomings to this approach which I must address at the outset. First, the field instrument focuses on the current occupants of land, as opposed to the displaced agents themselves. Given that the surveyed parties are likely to be more familiar with their own stories and motivations, as well as the processes and factors that led to their decision to sell land rather than with the previous landowner's, the information they provide is likely to be of a lesser quality (if available at all). In a number of cases the present owner was unfamiliar with the current owner's location and occupation, let alone the reasons which drove them to sell. Further, the buyer's understanding of the decision of the seller to sell may differ from the seller's actual decision making process. For example, a sellers' perception that they received an exceptionally high price for their property and a decision to cash in on a rapidly appreciating investment may not be perceived (or acknowledged) by the purchaser, who may have believed himself to have received a good price for the property. It is also probable that the current owner is more likely to be familiar with the location and occupation of the former owner if the former owner has remained in the area, a potential source of bias in the results. While acknowledging these potential sources of bias and inaccuracies, this survey nonetheless posed several questions to the current owners regarding why the former owner decided to sell their land and, if so, their current location and present occupation.

In forty-three of the fifty-four surveys the current landowner professed at least a general understanding of why the former landowner decided to sell his land. The reasons given were grouped into several categories, namely (a) relocation and reinvestment, (b) financial difficulties, (c) old age, and (d) non-agricultural issues, typically involving family problems or settlements related to divorce and family breakdowns. Decisions to leave ranching and invest in other sectors were also included under non-agricultural issues. When the current owner was unaware of the motivations underlying the sellers' decision the result was categorized separately as (e) unknown.

From these categories, the most common indication was that the former owner had sold his (there were no given responses where it was a she) land in order to reinvest or reconstitute his operations elsewhere. In total, twenty-one of the forty-three sellers were believed to have sold their land in order to reinvest in a new location. This answer was closely aligned with the framework laid out in the previous chapter; where farmers would take advantage of the rising value of their land and a spatial disparity in land prices to enlarge their operations through relocation (see figure 6.12). It is also indicative of the cascading effects of land use change and land appreciation. Evidently, the same decision making process that drew buyers from the south and the consolidated agricultural areas of Mato Grosso was propelling landowners in the consolidating agricultural and ranching districts to seek more land in emerging frontier areas. In this sense, just as a chance to take advantage of the disparity in land prices had drawn farmers and ranchers into the region, so too was it pulling them out of it. The reinvestment and relocation category, it should be noted, also includes timber companies, which would sell depleted timber lands in emerging frontier regions to incoming farmers or ranchers and seek new properties in new locations.

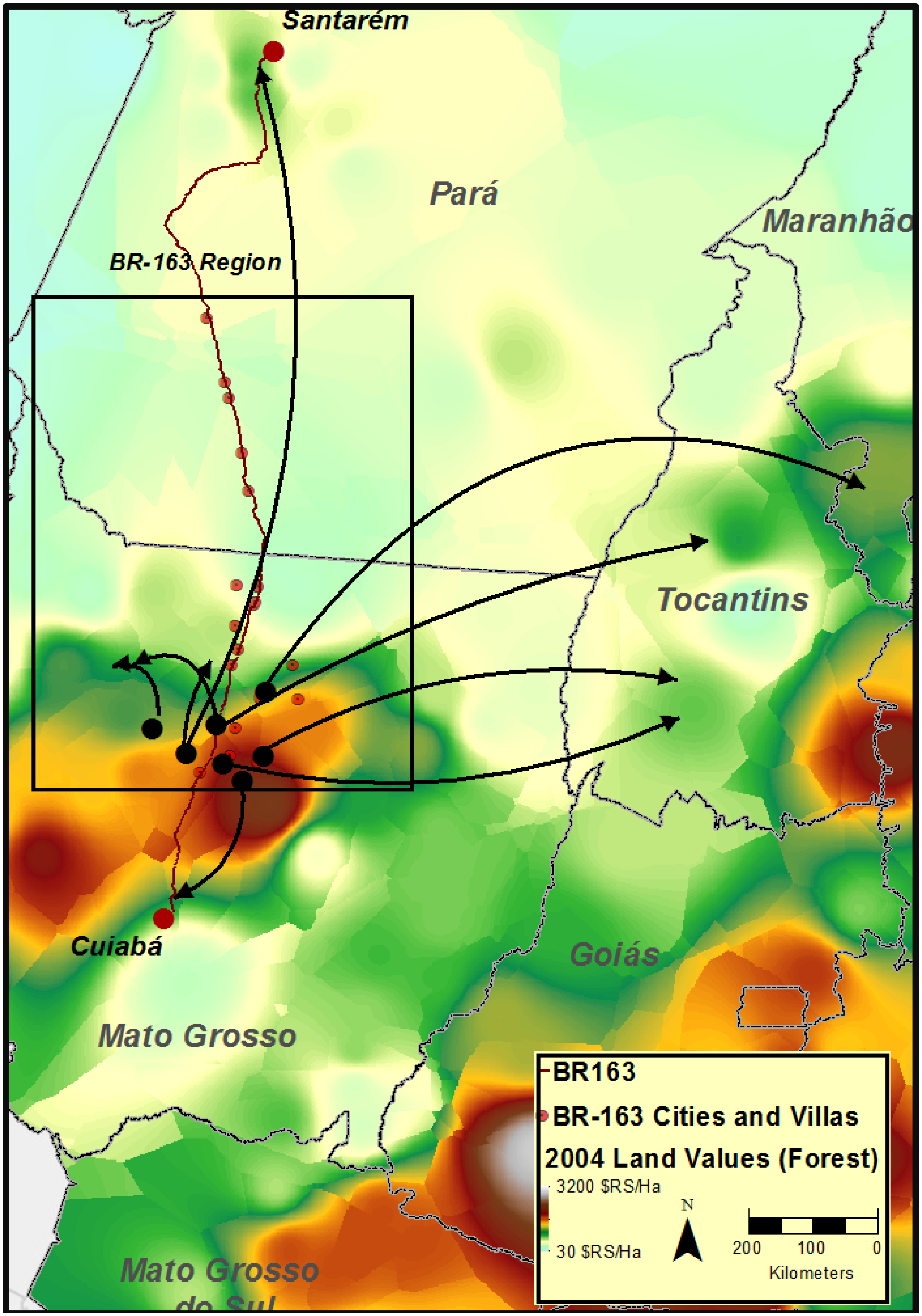

Figure 6.12.. Farm displacement trajectories of selected former landowners from the BR-163 region, shown over land values for forest. *Out-migrations shown to Tocantins and Maranhão are proximate and not exact.*

While a decision to relocate and reinvest in agriculture is aligned with the theoretical positioning of this research, landowners indicated that other reasons also factored into the sellers' decisions. The second most common reason mentioned by the purchaser regarding the sellers' decision to sell was financial problems. Of the forty-three responses given, I classified ten as pertaining to financial issues. The specific genesis of these financial difficulties themselves ranged widely, from difficulties acquiring financing (often owing to excessive clearing of forest cover and an inability to provide the required environmental documentation), to owning land areas in excess of legal limits, and other issues related to traditional financial risks of agricultural such as lower than expected prices and an inability to satisfy creditors.

Of the remaining responses, I classified six as old age and six as tied to non-agricultural issues. I found old age or non-agricultural issues to be more common at the frontier regions or on large properties where the inheriting party resided far from the ranch or property in question and the new owners were not interested in or not able to maintain its productivity. The non-agricultural issues, as explained earlier, consisted largely of issues related to divorce or arguments between family members or former partners. Multiple respondents suggested that their property simply has "too many chiefs", as brothers or cousins found their cooperative agreements untenable. Other non-agricultural issues included health problems and a desire to return to the comforts of home farther south or the superior medical treatment of the southern states of Brazil.

I must also note that within this survey data, just as with concentrations and migrations, a temporal shift is present from land sales for reinvestment and relocation toward sales derived from financial difficulties and non-agricultural issues. An examination of the previous landowners' motivations for selling their property over time indicates that relocation for reinvestment was most common from 2000 to 2003, but declined in more recent years (Figure 6.13). Arguably, I can link this shift to two factors. First, whereas the rapid appreciation of agricultural land during the earlier part of the decade incentivized relocation and reinvestment, the retraction in land values (2005-2007) and then only modest appreciation (2009-Present) acted to quell these incentives. Second, new policies designed to mitigate forest loss have created new obstacles to opening land. Whereas at the turn of the millennium and during the height of the soybean boom farmers and ranchers might have identified forested land as holding the potential to be cleared and put into production, and have had a reasonable expectation that they might be able to succeed in realizing this potential, in more recent years this expectation has been tempered. Farmers and ranchers are increasingly aware of new policies and controls that could prevent their expansion.

It also stands that in previous years, amidst the rapid appreciation of croplands, forests, and ranchlands, farmers and ranchers who had encountered financial difficulties might succeed in selling their troubled properties and still reap a capital surplus sufficient to relocate their production. Thus farmers who had gone bankrupt in Sorriso or Lucas do Rio Verde, or even Sinop, looked to purchase new lands farther north in Santarém, in the newer emerging soybean frontiers in Tocantins and Maranhão. Without the rapid appreciation of land and the broad disparity in land prices, however, this option becomes less feasible, possibly contributing to the decline in sales with the intention to reinvest spatially. It is also significant that the trend in recent years toward land concentrations, as opposed to migrations, is evident in the sellers' decision making processes.

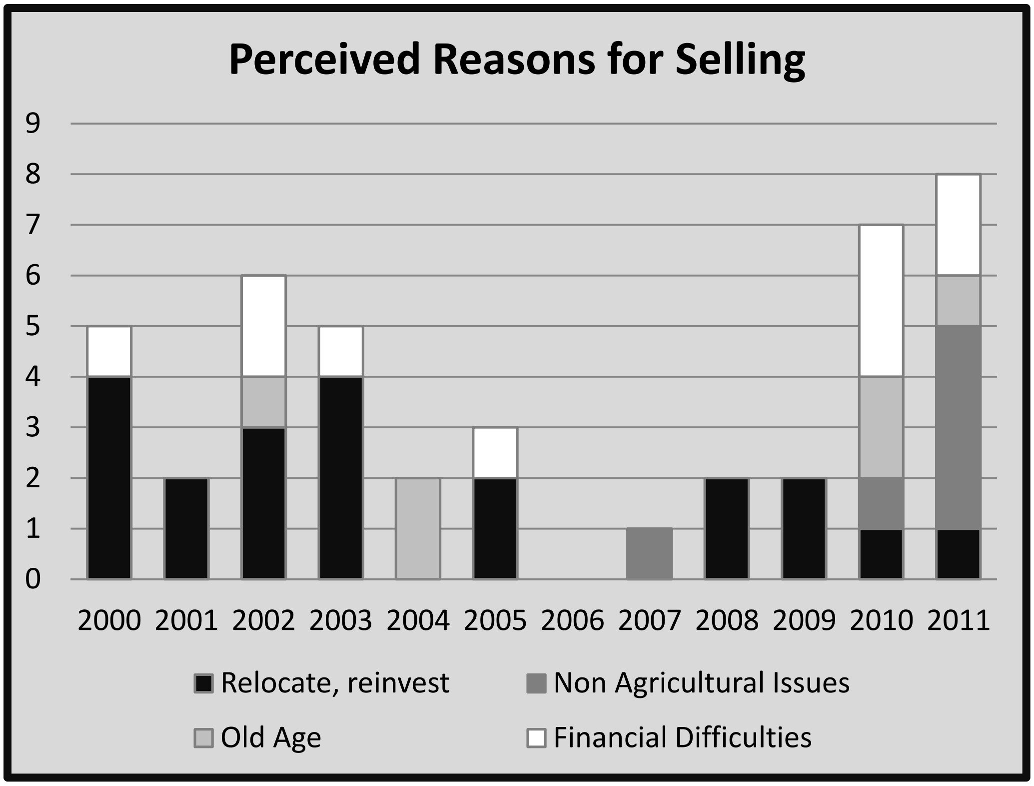

Figure 6.13. Motivations underlying farmers' and ranchers' decisions to sell.

6.3.5. Relocation and indirect land use change

The final set of survey questions considered the present day location and activity of the former owner(s). Just as with the seller motivations presented in the previous subsection, this information was less complete, given that I acquired the information through a third party rather than through the actual subjects of interest. In ten of the cases the current location or destination was unknown; in many others the exact present location of the former landowner was also of a less precise nature. Where the seller had relocated out of state, I was often only able to find out the destination state of the seller, as opposed to the exact municipio, which was provided in the case of the current landowner's origins.

With these restrictions in mind, sellers were classified as (a) unknown in their destination and current occupation, (b) retired, which included the deceased and those who have pursued new occupations (a classification in agreement with the location utility model in Chapter IV), and (c) displacement. Eighteen of the fifty-four responses indicated that the seller was effectively retired, whether through death or investment in another industry. In various cases the seller had invested in other sectors, whether in hotels, automobile sales, or other ongoing business pursuits outside of the region. This appeared to be particularly common where the previous owner did not reside in the area but rather lived elsewhere, be it in the Mato Grossense capital of Cuiabá, São Paulo, or the State of Paraná.

The interest of this study, however, truly resided in the residual effects of property sales, or in the relocation of human and financial capital. Consequently, I focused particular attention on those that have continued in their occupations. Of the twenty-six sellers that continued on in their occupations and, presumably, reconstituted their means of production elsewhere, the majority (fifteen) were farmers. Of the remainder, eight were active timber companies and three were ranchers. Of these twenty-six sellers, the average property size was 1,625ha, totaling 43,892ha. I found that the present or previous owners had opened nearly half of this land, with an average of 1,000ha opened per property purchased.

As might be expected, selling agents exhibited a higher average age than purchasing agents. Of the forty-two instances where the interviewee was able to supply an estimated age of the seller, thirty-one indicated that the seller was over fifty-two years old (figure 6.14).

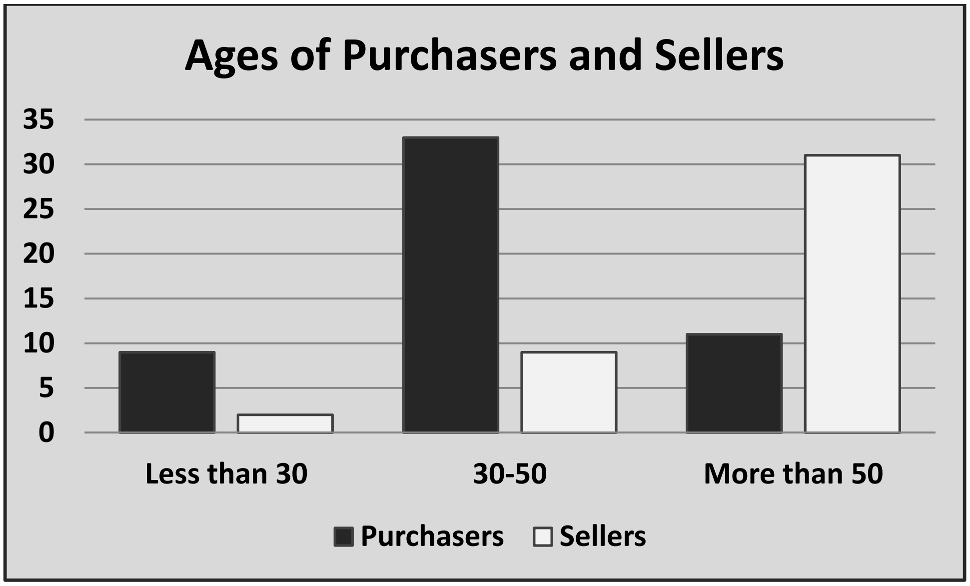

Figure 6.14 Age Distribution of Purchasers and Sellers

The results suggest that farmers are likely to relocate and continue farming than ranchers, a behavioral artifact linked to the intensity of skills invested in the profession. From my interviews, it was clear that many farmers identified closely with agriculture as a profession. Those that left sought to continue their production in new locations, usually by relocating to new agricultural frontiers. The relative rarity of ranchers leaving the region appears to be due to several factors. First, the extensive nature of ranching, and the tendency of some property owners to live outside of the region, suggests that in many cases ranching may not be the owners' primary rent generating activity. In certain cases, for example, it was clear that while the previous owner had maintained a ranch deep in the Amazon their principal activities were in other sectors. Second, in contrast to farmers, those ranchers who were residing in ranching areas may have been engaged in the activity more by an accident of location and market access than by trade. For example, for those who had arrived to the region with the intent to capitalize on easily acquired land, the creation of pastures signified a means by which to consolidate a claim on their property rather than as a consolidated occupation. In other cases, I found that the initial settlers were farmers who, with the realization that a region's inaccessibility limited their capacity to profitably produce market based commodities like coffee and rice, decided to revert their production to the only viable economic strategy in remote frontier regions, namely ranching. In this sense, ranching, as an economic strategy, might have been more of a default option than a choice. However, as ranchers' lands appreciated in value, or as the demand for their land increased, some of these "accidental" ranchers took the opportunity to liquidate their land assets and reinvest in other sectors. In other cases, cattle rearing was not the landowner's principal economic activity, but rather was an activity ancillary to other pursuits, some of which may have been tied to distant regions or locations.

While the notion of fixed human capital presented in the previous chapter appears to hold for commodity farmers, it is less clear as to how it pertains to ranchers. To some extent, this finding reflects the changing reality of Amazon land use as commodity markets expand their reach into the region. Soybean farmers and some ranchers view land as a scarce production input that is central to their trade. In contrast, ranchers and small farmers who arrived to the region over the previous decades and who viewed land as a speculative investment, as parcel to a broader investment portfolio, or as a means by which to extend a semi-subsistence mode of production, may not possess the skills with which to engage in soybean production but may seek to reap the returns of their appreciated land. The latter group may not be as fixed to their production strategy; I argue, rather, that their strategy of speculation was never truly tied explicitly to the use of the land. The recognition of divergent views on relations to land between the legacy owners of Amazon ranches and recent arrivals focused on commodity production is largely aligned with the findings of Adams (2008), who reflected on the divergent relations to land exhibited by a local, historical elite and soybean producers.

The role of timber companies within the displacement landscape is also highly ambiguous, given the spatially diverse portfolio of landholdings possessed by many of these operations. Historically, at the outset of the colonization of BR-163, colonization companies conceded many of the region's more inaccessible locations to timber companies, who consequently possessed large tracts of land on the fringes of the Xingu reserve and in western Pará. In many regions, timber companies have sold much of this in comparatively smaller parcels to incoming ranchers or farmers. Some of the timber operations remain based in cities such as Sinop (though some are also tied to landowners residing in distant cities, including São Paulo), but operate across a broader region, from farther north in Pará, to northwest Mato Grosso. Given the heterogeneity of timber holdings, it is difficult if not impossible to pinpoint a specific displacement effect associated with a land transfer. However, in key informant interviews and in some of the surveys mention was made of new timber purchases made afterward, occurring both elsewhere in Mato Grosso and in Amazonas State (located to the west of Pará). Nevertheless, the results of this work have indeed documented instances of ranchers and farmers purchasing degraded tracts of land (formerly exploited by timber companies) for conversion to either ranchland or croplands. And while the documentation of timber operations' displacement was difficult, the general concept of inter-sector capital transfers and the spatial relocation of capital remains.

While the motivations for selling are in general agreement with the theoretical framework outlined in chapter IV, the survey data was ambiguous with regard to hypothesis **H2.5**. For while farmers and timber companies indicated that they sought to exchange their lands in consolidating agricultural and pastoral areas to relocate to the frontier, the process was less defined with ranchers. In fact, there were no instances of ranchers reporting that their former properties were now in use by soybean producers. This is not to say that the displacement process is not occurring; only that a spatial linkage is likely more complex than originally believed. It is not necessarily the movement of individuals from one point of change to another, but rather a cascading effect as the movement of ranchers and ranch sales results in higher land prices and the gradual increase in producer incentives to sell (and potentially relocated).

6.4. Tying together farm level decisions, displacement, and indirect land use change.

This chapter provided field level documentation of the in-flows and out-flows of immigrants associated with the agricultural and ranching sectors. I designed the chapter and the survey to offer a more complete understanding of the spatial redistribution of human and financial capital associated with the expansion and relocation of ranching and soybean production in the Amazon, as well as the motivations underlying relocation and migration. By focusing on the BR-163 region specifically, and then documenting both the origins and decisions of the purchasers and the destination and motivations of the sellers, it provided an explicit link between decisions and land uses in multiple locations. In effect, it documented channels of resource flows, indicating both the broader spatial causes and the subsequent effects tied to land use change in the BR-163 region. It did so by examining farm level incentives for not only production, but also location, and situated these incentives within a larger rent based structure tied to changing land prices and market access.

The results recognize the importance of migration and land transfers in land use change in the BR-163 region. They indicate that these drivers and impacts are dependent not only on changes occurring within the region, but also on those occurring in potentially distant locations. Notably, this work provided evidence that migration into the Amazon region, particularly from the agricultural strongholds of southern Brazil, has continued to both deliver and displace human and financial capital. These findings are generally supportive of the final hypothesis associated with objective 2, **H2.6**, or that indirect land use change occurs through the displacement or movement of skills and capital from one region to another.

However, while recognizing that the broader spatial impacts implicit in the migration and land use change processes are indeed evident, it must also be acknowledged that the rise of Mato Grosso (and of the BR-163 region on its own), into a consolidated agricultural stronghold in its own right has reshaped the frontier dynamics of the region. The results of this work, while showing evidence of a past trend of south to north migration during the early years of the millennium and at the height of the soybean boom, also suggest that this pattern has abated in the most recent years. Since 2007 increasingly powerful reserves of agricultural capital in Mato Grosso have come to dominate the region, enabling a shifting pattern of land purchases and accumulation, from one dominated by in-migrants to one dominated by the new economic elites of the region. To quote one now well established rancher in Pará, today "one comes to the Amazon as either a pawn or a patron;" indicating opportunities for both great risk and reward have diminished as the frontier has consolidated. Given that land values for prime, well positioned and accessible agricultural land in the BR-163 region now rival those of south, and that landowners in the Amazon can increasingly use their massive properties to leverage the capital required to purchase new lands here, this trend is likely to continue. As access across Mato Grosso to new markets, facilitated by new export corridors and the development of better highways, railways, and waterways continues to improve and diminish the spatial disparity in land prices between the south and areas of the Amazon, this trend is likely to continue.

The displacement effect and the linkage between the advancement of the agricultural and cattle frontiers hypothesized as occurring within the BR-163 region, however, was less clear and more spatially complex than expected. The expected trend of farmers and ranchers moving northward along the influence of BR-163 was indeed present, but not of the presumed magnitude, as farmers and ranchers were just as likely to seek advantages beyond the BR-163 region as within its confines. In this sense, farmers searched statewide and even nationwide for opportunities for relocation, and in some cases re-established their operations in very distant locations, some even outside of the Amazon. Nevertheless, this research confirms that migrating farmers or ranchers choose to relocate from one location to another based on a function of disparity in land prices and distance or knowledge (Sjaastad 1962, Richards 2012).

The displacement process in the BR-163 region was more complex than originally conceived. This was particularly true for ranchers. In effect, Novo Progresso and Castelo dos Sonhos represented a true cattle frontier, however, ranchers' arrivals to these regions, appeared to be not from farther south along BR-163, but rather from elsewhere across Brazil and the Amazon. Recent arrivals to the region had come not from northern Mato Grosso, but from Paraguay, from Rondônia, from elsewhere in Pará State, or from ranching districts in Tocantins or Goias. Few property owners from farther south in the BR-163 region appeared to consider western Pará as a potential region for continued expansion. Ambiguities in property ownership in Pará and recent but ongoing attempts to clarify property boundaries have, in recent years, largely stalled the property market and constituted an obstacle to growth in the region. And of those that had sold their land within western Pará, few had sold their land with an intention to relocate their operations elsewhere. Evidently, while western Pará has become increasingly accessible to northern Mato Grosso, bureaucratic obstacles pertaining to an ability to bring new land into production and insecure property titles have diminished incentives to relocate into the region. In fact, partly owing to these issues, many of the property owners interviewed for this study suggested that, were they to move again or to buy new land and reconstitute their operations once more in a new location; they would look to do so not only not in Pará, but also outside of the Amazon in general. Maranhão and Tocantins, two recently emerging agricultural frontiers located within the Legal Amazon, but outside of the Amazon biome (and thus the restrictions that follow), were often cited as possible destinations.

If the displacement outcomes were more complex and spatially diffusive than expected, the decision on where to relocate remained in general agreement with behavioral framework structuring this analysis. Farmers' and ranchers' decisions to migrate were clearly a function of distance, price, and the potential to farm or raise cattle. For those already possessing established extensive agricultural or ranchlands in the region, new purchases were contingent on access, with the decision to add to their holdings dependent on access from their current residences or farms, price, and the possibility that the parcel would constitute a favorable investment in the future.

6.5 Results and Conclusions

The second objective of this research was to clarify the movements and distribution of people, skills, and capital within the Amazon. The first of the stated hypotheses, namely **H2.1**, was that agricultural changes occurring across Brazil, specifically in regard to land use, wield an impact on land use change in the Amazon. The results appear to confirm this hypothesis. Evidently, small or medium scale capitalist farmers, many from consolidated farming regions in

Brazil's southern states, have migrated to the margins of the soybean frontier in Mato Grosso. The magnitude of this migration was highest during the beginning of the study period, or between 2000 and 2003 at the height of the soybean boom and a period of rapidly rising land values. Additionally, ranchers had arrived to western Pará from consolidated ranching districts in Paraná, Goias, and portions of eastern Paraguay inhabited by Paraguayans of Brazilian descent, in these cases seeking to return to their ancestral nation. While the reasons for these migrations vary (and will be discussed in comments directed toward hypothesis **H2.2**), it was clear that land use dynamics in these distant regions played an important role in incentivizing their migration into the Amazon.

Though this dissertation has confirmed that distant forces continue to shape migrants decisions' to relocate their skills to the Amazon, it also suggests that these broader linkages have abated in recent years. A combination of rising capital accumulation in Mato Grosso and rising prices for land, particularly in the most accessible areas near the margins of BR-163, has meant that farmers and ranchers from distant regions may no longer possess significant (human or financial) capital or production advantages over their peers farther north. Rather, the most recent patterns of land use change in Mato Grosso appear to be fueled by capital and skills disseminating from the rapidly consolidated agricultural districts within Mato Grosso itself. In this sense, successful farmers and financers in Mato Grosso have been able to leverage the increasing value of their lands and their political influence to drive the frontier outward. This is largely congruent with recent suggestions that the growth in soybean production, while leading to overall economic growth and poverty reduction, may also increase inequality (Weinhold et al. 2011).

This dissertation research also confirmed the second hypothesis tied to objective 2, namely that farmers and ranchers who relocate their operations do so to maximize their access to land, and thus the marginal utility of their economic skills (**H2.2**). Nearly all of the migrating farmers and ranchers interviewed had suggested that their principal motivation for purchasing land was to amplify their holdings, both to increase their current production and to capture what was felt to be a secure investment for the future (given the rapid rates of appreciation seen over the past decade). Given that the structure of land distribution elsewhere in Brazil limited potential expansion, particularly in the south, where land is distributed in smaller parcels, or in the traditional cattle regions of Goias, Minas Gerais, or Tocantins, where land is consolidated in large, *latifundia* ranches, the Brazilian Amazon region provides one of the few outlets where smallholder and medium size farmers have the possibility to come into the possession of larger parcels. As producers increase their efficiency through mechanization and new technologies, they need fewer farmers to work their land. For both farmers and ranchers, maximizing the utility of their skills would require either the purchase of neighbors' land or their relocation to areas such as the Brazilian Amazon, where they could feasibly acquire larger parcels. The results shown in table 6.5 indicated that in every case where I recorded a migration the purchaser reported a significant increase in property size, ranging from forty-three to more than four thousand percent, with the highest increases recorded for those who had relocated to the most marginal locations

Hypotheses **H2.2** leads immediately to hypotheses, **H2.3**, or that the decision of *where* to locate is a function of distance and (difference in) price. The conceptual model presented in Chapter IV describes the decision of where to move as one of opportunity costs, which itself is a function of (more) known rents in one location and potential (but less known) rents in another, possible production location.   At least within the abstract, Thunian model presented as a conceptual manifestation of the Amazon landscape, the more marginal the land sought for purchase the lower its price will be. For both ranchers and farmers seeking to increase their land holdings, this hypothesis suggests that they will look to balance risk (increasing with distance) with reward (more land) by obtaining the nearest land suitable for production at the least cost.

In the results that I present in section 6.3.2 I confirm this hypothesis. In some cases the new owners of recently acquired land stated this tradeoff explicitly and cited it as one of the principal factors leading to their decision to purchase their properties. Respondents also stated that the difference in land prices between prior locations and the most recent purchase was a determining factor. For those farmers who had arrived from the south, many during the height of the soybean boom, the rapid appreciation of their land increased the amount of potential capital available for investment. By selling off a smaller property in a more consolidated agricultural district, they could acquire a far larger parcel in Mato Grosso or western Pará. The price differential, it appears, factors not only into *why* (**H1.2**) to migrate but also as to *where* (**H1.3**).

The fourth hypothesis (**H1.4**) specified under objective 2 is that land use changes occur with changes in control over land, and that the relocation process amounts to a spatial redistribution of skills and capital. I confirmed this hypothesis through the field results, where 34 of the 54 parcels surveyed underwent a land use change after purchase. Here, it was apparent that incoming migrants or local producers looking to expand had identified an unrealized potential for production. The prior owners had, evidently, identified the opportunity costs of possessing lands that another landowner might employ to garner higher rents. By selling their land the former owner thus obtained a portion of the higher rent generating capacity (which they could use to open new land for production elsewhere).   The arrival of new skills and capital with the new landowner implied an arrival of new resources, essential to a property's ability to generate maximum rents, and thus constituted a defining impetus to regional land use change.

I designed the final two hypotheses to directly approach the issue of indirect land use change through queries of the present day activities of those who had sold their lands to incoming farmers or ranchers. The first of these hypotheses, **H2.5**, would be confirmed if new ranches had been reconstituted in areas of recent deforestation from pre-existing locations now used for soybean cultivation OR if new croplands used for by incoming soybean farmers had indicated that the former landowners had engaged in ranching, and upon leaving relocated their ranching operations at the expense of forest cover. Confirming H2.5 turned out to be a difficult maneuver, as the spatial direction of expansion of ranchers did not appear to flow from the soybean regions of Mato Grosso into or toward the cattle frontiers of western Pará. Only a single case of a rancher selling their land to a soybean farmer and relocating to the frontier was documented; and in this example, the displaced rancher had relocated to another district in western Mato Grosso, not to Pará. Technically, this single case would be sufficient to suggest that indirect land use change has occurred, though it was unclear and unknown as to whether or not land use change was incurred through the relocation of the rancher in question. Of those ranchers surveyed in Pará, the majority had come from already consolidated cattle frontiers from within the Amazon or from the established ranching zones elsewhere in Brazil, including Goias, Mato Grosso do Sul, and the southern state of Paraná. In none of these cases did the rancher suggest that those who purchased their old properties were using these lands for soybean production.

Had I revised **H1.5** to suggest that ranches OR timber operations reconstituted themselves upon displacement, then I could confirm this hypothesis. Many of the cases where the old owner had moved on had involved timber companies who had exchanged exhausted, degraded forest tracts for more (apparently) less exploited tracts in more remote locations. While this certainly constitutes a form of indirect land use change, it was not of the variety expected, nor needed to validate the conclusion, as the intention of this research was to document ranchers displaced by soybean farmers. As will be suggested in the following section, however, this is not necessarily a contradiction to the conceptual framework of this analysis, but rather that the effect may be manifest through channels which I did not capture in this analysis. Alternatively, it suggests that the presence of direct land use change from forest to soybean production in northern Mato Grosso may have limited the indirect effects emanating from this region.

Confirming the final hypothesis, **H2.6**, or that indirect land use change in the Amazon occurs with the displacement and relocation of skills and capital to the frontier, is complicated by my inability to provide a resounding confirmation of hypothesis **H2.5**. What is clear, however, is that land use displacement is indeed present, as farmers and ranchers reinvest their skills in locations where they can increase their access to land. As prices for land rise in consolidated agricultural and ranching regions, so too do opportunities for landowners in these areas to leverage these properties to acquire larger parcels at the frontier. This premise rests upon rising land prices, which themselves are contingent upon changing market conditions and the demand for land capable of either cultivating commodity crops or rearing cattle. While these conditions were present, and the displacement effect was clearly evident, drawing explicit linkages between land use displacement and indirect land use change, however, was not necessarily possible, as those who had sold land to incoming farmers were either (a) timber companies who had expanded their operations, but did not necessarily fully deforest upon relocation; (b) farmers who had relocated their operations to new agricultural frontiers; (c) ranchers who had reestablished production, but whose land cover impacts could not be confirmed, or (d) retirees who were no longer pursuing agro-pastoral based rent generating activities.

The information collected for this analysis indicates that the cascading land use effects associated with land use displacement are more complex than originally perceived, and the displacement process may emerge through multiple land sales before indirect land use change is manifested. I must thus recognize that there remain certain limitations to justifying these hypotheses, as the cascading effects of land use may not result directly in indirect changes, but also to displacement tied to consolidations occurring in agricultural districts. This later effect, however, would likewise act to dispel human and financial capital from established agricultural regions to frontier areas.

6.6 Limitations of Field Results

When considering the results presented in this chapter, several limitations must be considered. Most notably, the survey captured only a limited number of respondents who had made their land purchases over a large and diverse study region. Seeking out recent landowners in this area was by no means an easy task, particularly in the sparsely settled frontier regions that were the subject of this analysis; however, the conditions notwithstanding, the fact remains that the number of surveys conducted in comparison to the broader population remains small. Nevertheless, the broader patterns ascertained in the field survey are suggestive of several salient patterns and processes. However, in recognition of these limitations, the data was used only for descriptive purposes rather than for empirical analysis.

Another limitation to the data collected is that I focused on finding large landholders in the region, and smallholder producers may have been omitted from the broader analysis. This was done to some extent intentionally, given that larger landowners are more likely to be fully integrated into the market and respond to shifting rents and market opportunities. Large landowners were also more likely to possess significant levels of skills and capital tied to the commercial production of agricultural commodities or beef. Smallholder farmers, in contrast, were more likely to employ land uses strategies focused on semi-subsistence production or non-market agriculture, and less likely to possess the resources deemed so important to the displacement and indirect land use change processes. Admittedly, I omitted smallholder farmers from this analysis also for practical regions: by focusing on large properties I was able to employ the network of producers' associations that is organized across Mato Grosso and, to a lesser extent, in western Pará, thus facilitating data collection. Nevertheless, it is indisputable that smallholder farmers were indeed present in areas at the very north of Mato Grosso, including in Peixoto de Azevedo and Guarantã do Norte, as well as in Novo Progresso in Pará; and all of these regions have incurred significant levels of deforestation in recent years However, in only one case, in Guarantã do Norte, did a rancher indicate that he had compiled his ranch from smallholder farms. In that case, the displaced farmers, he reported, had purchased and opened new plots in nearby regions.

CHAPTER VII

CONCLUSIONS OF THE DISSERTATION

7.1 Introduction

The Amazon region, long marginalized at the periphery of Brazil's political economy, has in recent years undergone a transformation from economic backwater to a leading engine of capital production and economic growth. The untapped potential of the forest resided not in the canopies of its extensive strands of centuries old hardwoods and semi-pristine lost waterways, but within the soils upon which the forest once stood, and in the waterways that course its valleys.

No longer is the Amazon merely a refuge of social migrants seeking to escape drought or vacuums of economic opportunities in the nation's northeast or densely populated rural districts in its southern states, nor of speculators and the politically and commercially connected searching for public subsidies or itemized deductions on their accounting sheets. Rather, over the past decade the economy of the Amazon has transitioned into an integrated provider of beef and soybeans, provisioning sustenance not only to Brazil, but to the world over. New technologies have emerged to enable the production of these commodities, and the skills and capital that enable their deployment for economic gain have streamed into the region. The resulting cocktail of skills and market based opportunities, combined with the Amazon's traditional abundance of the now most limited of unnatural commodities, land, has rendered the basin into a land of opportunity and increasingly realized economic power and potential (Walker et al. 2009b, Richards 2012) .

Realizing the economic potential of the region, however, has come at a clear environmental cost. And the conversion of the Amazon from a wilderness to garden is not without its own challenges, as the tenuous balance between growth and conservation is continually contested, altered, and reformed. A rapid rise in deforestation in the Amazon from 2001 to 2006 followed the heels of the rapid expansion of croplands and cattle populations from 2000 to 2004 (INPE 2011, IBGE 2011b, IBGE 2011a). This dissertation engages with the ongoing discussions over how to achieve security in food and fuel without destroying the environmental balances upon which this security ultimately rests. Achieving a tolerable equilibrium is unlikely (and may never be possible); given the dynamics of markets and their active role in defining and deflating incentives for land cover change in the region. However, a better understanding of how a dynamic and diverse set of actors and structures in the Amazon interact and affect the environment will greatly assist policymakers, farmers, and frontier ranchers alike in setting the region's development to a course toward a sustainable future (Babcock 2009b, Arima et al. 2011, de Sá, Palmer and Engel 2012, Hertel et al. 2010b, Kretschmer and Peterson 2010, Lapola et al. 2010, Pingali, Raney and Wiebe 2008, Searchinger et al. 2008, Fargione et al. 2008).

Academics have already provided a tremendous wealth of information on the drivers of deforestation, and on the linkages between social and economic processes and land cover change. In many of these cases, the models have been directly applied to understanding the specific processes and policies of the Amazon (Aldrich et al. 2011, Labarta et al. 2008, Fearnside 2008, Ewers, Laurance and Souza 2008, de Sherbinin et al. 2008, Browder et al. 2008, Simmons et al. 2007, Pontius et al. 2007, Pan et al. 2007, Caldas et al. 2007, Brown et al. 2007, Soares-Filho et al. 2006, Nepstad et al. 2006, Jepson 2006a, Soares-Filho et al. 2004, Arima et al. 2004, Chomitz and Thomas 2003, Rudel et al. 2002, Kaimowitz 2002, Alston et al. 1999, Pichon 1997, Hecht 1985, Branford and Glock 1985, Sawyer 1984, Mahar 1979, Walker 2011a, Walker et al. 2009c, Walker et al. 2009b, Walker 2003, Walker and Homma 1996). With the recognition of a shift towards the globalization of the Amazon, research on land cover and economic change here has also acknowledged a shift in the broader political and structural forces that direct both capital and farmers into the Amazon (Macedo et al. 2012, Bowman et al. 2012, Weinhold et al. 2011, Walker 2011b, Galford et al. 2011, Arima et al. 2011, Pfaff and Walker 2010, Mann et al. 2010, Lapola et al. 2010, Galford et al. 2010, Barona et al. 2010, Walker et al. 2009c).

I situate this dissertation within this later field of research on Amazon land use change. I consider structural factors and links market based incentives to field level changes in production decisions and the movement or migration of human capital. In doing so, I break from much of the recent research on land use change in the region by not only considering how market based dynamics pose new challenges to the region, or incentivize the creation of new pastures or croplands, but also the residual or indirect effects associated with these changing conditions. Specifically, I have drawn on longstanding concepts concerning the spatial mobility of labor (Sjaastad 1962, Carr 2009, Todaro 1980) and situated them within a landscape built on spatially explicit concepts of rents (von Thünen 1966, Dunn 1967, Alonso 1964, Ricardo 1891). The result is an innovative conceptual approach within which to frame the indirect effects of land use change as a displacement process. In doing so, I consider not only broader scale, often international level, acreage responses to market dynamics, but also inter- and intra-regional spatial flows of resources. These flows, which in the past have often been overlooked, or which have been examined largely as a social issue, wield significant impacts on land cover in the Amazon and, most likely, in other regions undergoing rapid land use change.

The structure of this dissertation was thus one that, after recognizing the broader historical and political-economic forces that have shaped the region, first sought to better understand the flow of resources at the field level through surveys and key informant interviews. The behavioral processes and structural incentives that were observed to be driving migration and hence, the displacement effect conceptualized in Chapter IV, were then modeled over Brazil, with the Amazon as the theoretical point of impact. In the scheme of this dissertation, if Chapters IV and VI were designed to contribute to the understanding of *how* land use changes indirectly result in broader ecological impacts, Chapter V provided an estimation of *how much*, or the degree to which indirect land use change derived from expanding croplands has resulted in deforestation. While the methods and means by which the study stands are by no means without fault, they do provide a multi-scale perspective and mixed method based approach that takes into account a complex array of production factors.

7.2 Principal Conclusions of the Dissertation

Principally, this dissertation sought to provide evidence of the linkage between the expansion of the Brazilian agricultural sector and the loss of the Amazon forest. As one of the world's largest remaining regions with extensive land reserves, Brazil, and the Brazilian Amazon in particular, is likely to face intense pressures for agricultural development in the coming decades (Masuda and Goldsmith 2009a, Masuda and Goldsmith 2009b, FAO 2009). The recent growth in agriculture appears to have already fostered economic benefits, particularly in regard to poverty reduction (Weinhold et al. 2011). However, a better understanding of the full effects on the environment derived from the growth of agriculture will help to guide policy makers seeking to balance this new economic growth with the region's environmental value. The empirical conclusions arrived at in this dissertation suggest that the growth in cropland in Brazil has contributed to overall deforestation in the Amazon and specified an estimation of its effect.

In this dissertation I also further developed the conceptual processes that underlie indirect land use change. Here I shifted away from the general and partial equilibrium models from land economics and toward a re-conceptualization of the process as one driven by the spatial redistribution of human and financial capital (Richards 2012). As I argued in this dissertation, while the broader dynamics of supply and demand and supply losses associated with cropland conversion in the U.S. or elsewhere are likely to influence crop dynamics in places such as Brazil, nation-specific contextual factors such as the exchange rate and other internal dynamics such as the existing land use structure will mediate the effects (Richards et al. 2012). Within Brazil, any indirect price effect of soybean production on the expansion of cattle production derived from displaced pastures, for example, would to be minimal. Between 2001 and 2004 farmers converted less than 6,000 square kilometers of pasture to cropland in Mato Grosso (Macedo et al. 2012, Morton et al. 2006). Assuming a stocking density of these areas of approximately one animal per hectare or one hundred per square kilometer, this amounts to approximately 600,000 animals. Given that the Brazilian herd had by 2004 surpassed 70 million head (IBGE 2011b), the area supply loss would impart only a minimal, if any, regional impact on beef prices.

I thus view the indirect land change process as driven primarily through the displacement of skills and capital, and through rising land values. This conceptual development, described further by Richards (2012) stems in part from anecdotal mentions of the effect of land prices as a driver of expanding croplands and pastures (Nepstad et al. 2006, Cattaneo 2008, Macedo et al. 2012) and is in fundamental agreement with economic considerations of labor mobility as a driver of indirect land use change (de Sá et al. 2012). The results of the field work confirm this process of relocation and expansion, as farmers and ranchers willing to take the risk of moving to the frontier from areas of skill surpluses to areas with scarce skills being rewarded with greater access to land. This position reemphasizes the importance of recognizing resource flows as a principal driver of land use change. Specifically, by considering the destinations of the capital and skills liquidated and displaced with land use change, it links regional environmental change to larger changes in the structure and organization of Brazil's land based economy.

This is not to say that indirect land use change derived from new soybean production is inevitable. Rather, another critical conclusion of this research, one which has been only briefly discussed, is that recent policies enacted in the Amazon have been successful in, at least temporarily, lowering rates of forest loss. Increased enforcement and accountability (e.g., through CAR and LAR) for land use change has diminished rates of deforestation. Those who are out of compliance face potential difficulties in obtaining financing. For those with extensive reserves of accumulated capital or dependent on financing, facing the potential repercussions of deforesting illegally poses a daunting prospect. These changes, which were enacted after the spike in deforestation rates from 2003-2006, have recently come into effect. The effect of these policies is clearly evident from field level discussion with both farmers and key figures in both the soybean and cattle sectors.

Indirect land use change and its effect on the Amazon forest can only be mitigated by managing losses to the forest itself. Outside of limiting producer and capital mobility, a potentially impossible task in a capitalist democracy, only by bounding production areas and limiting new clearings (e.g., such as through the creation of protected areas and enforcement of existing policies) will the broader impacts of land use change on deforestation be mitigated

(Walker and Solecki 2004). As these policies have come into effect and deforestation is slowed, it follows that the indirect role of soybean expansion elsewhere in the nation will likewise be diminished, with evidence of this decoupling between soybean production and deforestation in recent years becoming increasingly visible (Macedo et al. 2012). Given the results of this work, to what extent this decoupling may be linked to the soy moratorium is unclear. Based on the conceptual models employed in this analysis, as well as through discussions in the field, however, it is likely to be minimal.

While this research indeed suggests that an indirect effect assumes a critical role in driving forest loss in the Amazon, it also acknowledges that the Amazon landscape, as well as the markets, policies, and institutions that have helped to shape it, are dynamic. Recent developments in the region indicate a slowing of deforestation at the point of the forest clearing, and a redirection of both farmers and ranchers either away from the Amazon Biome (towards Tocantins and Maranhão) or towards underutilized degraded or fallow pastures. This is a positive development for the Amazon forest and an important step in reducing the environmental impacts of the soybean and cattle industry in the region.

7.3 Broader Impacts

In addition to the direct implications of the principal conclusions of this dissertation, this work has also advanced several theoretical and analytical advancements which may be applicable beyond the immediate realm of research on Amazon land use change. First, the development of the spatial weights matrices based on land prices and transportation networks presents a significant advancement in the field of spatial econometrics. To my knowledge, I am the first researcher to employ a GIS based transportation network as a weighting mechanism in an econometric analysis. The utilization of a matrix of land prices also represents a significant advancement. Given that the fundamental premise of spatial econometric methods lay in the flows of influence, it follows that modeling the weights upon the actual flows of resources rather than on contiguity or Euclidean distance represents a significant advantage in accurately modeling these effects. Other researchers could apply these advances in spatial models employed not only for models of land use change, but also to many of the diverse subjects analyzed through spatial models.

This research has also contributed to an emerging literature recognizing the broader spatial impacts of changing market demands in an era of globalization (e.g Rudel et al. 2009, Pfaff and Walker 2010, DeFries et al. 2010). As suppliers connect new lands to consumers in potentially distant locations they also enable the creation of new areas of production. Elucidating the linkages between regional consumption decisions and distant environmental impacts continues to pose a challenge; however, as these new theoretical and conceptual problems arise, and as new methods and new ideas are devised to meet this challenge, these problems will be surmounted. I view both the empirical models and the field work conducted as part and parcel to this dissertation as implicitly contributing to this growing body of literature.

Finally, I view this dissertation as contributing to a broader discussion on the value and location of labor, and of migration within the context of a globalizing economy (Caviglia-Harris et al. 2012, Lambin and Meyfroidt 2010, Carr 2009, Barbieri et al. 2009, Fearnside 2008, de Sherbinin et al. 2008, Moran et al. 2005, Carr 2004, Rudel et al. 2002, Perz 2002, Geist and Lambin 2002, Andersen et al. 2002, Massey et al. 1993, Todaro 1980, Sjaastad 1962). Rural migration in tropical regions has long been studied, often as it pertains to semi-autarkic smallholder farmers seeking marginal lands. In this dissertation, however, rural migration is set within a market based landscape, where farmers and ranchers producing for a capitalist market view migrations as a means by which to maximize the returns on their skills. Conceptually, this is extremely close to the migration of peasant farmers; however, it is reconciled to the contemporary state of the Amazon, where market dynamics not only have shaped the frontier, but have drawn to the region those who possess the skills and knowledge appropriate to take advantage of these new opportunities.

Another broader impact of this dissertation stems from its multi-method, multi-scale approach to analyzing a complex system of land use and land use change in the Amazon. The dissertation recognizes that the drivers of change are not only complex, but that they are only constant in their perpetually changes. Today the expanding reach of global food demand, and the networks needed to deliver goods from producers to consumers a world away, has reshaped a global landscape of profit, employment, and activity. International trade, in fact has brought both opportunities and potential pitfalls to regions once dependent on national or even local conditions. The drivers of land use change will surely continue to change with time, and as new sources of influence and new demands touch upon and shape behaviors they will also shape landscapes.

In the preceding chapters I suggested that areas within the Brazilian Amazon have transitioned from relatively autarkic communities of smallholder producers, from isolated farmers struggling to produce for domestic markets, and from the assets of distant landholders clinging to the vestiges of a class that identifies with its extraordinary access to land, into inputs in the global belt of food production. I then turned specifically toward the growth and expansion of a sector that is representative of this economic shift, namely the soybean sector. Then, to fully understand the complex process through which the sector has not only grown, but affected the Amazon landscape, I employed a mixed-method, multi-scale approach.

In this dissertation I analyzed the effects of soybean expansion across Brazil on the Brazilian Amazon region as a whole, and on a study area at the heart of Brazil's arc of deforestation. I integrated an econometric analysis into a broader historical and political economic context, and grounded the results with field level work with ranchers and farmers, and with key institutional and sector specific contexts. This approach is reflective of the multi-method, multi-scale approach put forward by Chowdhury and Turner (2006), and is a holistic approach that is most capable of accounting for the broader forces directing human decisions on how to shape landscape and employ land, whether for family subsistence of the sustenance of humanity.

Future research and researchers on land use change in the Amazon must be prepared to take into account not only the factors and forces that have shaped land use change over the past decade, but also to take into account the forces and factors that will come to shape it in the future. Certainly, many of these factors we can predict; be they the market forces emanating from demand for high protein agricultural crops in Asia, or a growing middle class hungry for beef in Brazil itself. However, new forces and factors, presently unseen, will challenge both policy makers and producers in the coming decades. The future of the Amazon, and perhaps the futures of Brazil, and consumers across the globe, may depend on how we respond to the forces and factors that we do not yet see, let alone understand.

EPILOGUE

Step by step
All the happy Saints go marching in
And if one of those Saints step out of line
He'll have to start again
Cause Jacob's golden ladder
Get's slippery at the top
And many a happy-go-lucky saint
Has made that long long drop

"Step by Step"
Jesse Winchester

August, 2011, BR-163

Figure E.1. "Novo Progresso adheres to Illegal Deforestation ZERO"

Several weeks into my field work I was once again being dutifully advised to stay the course of my original research plan. I had by now accepted that, regardless of whether or not farmers or ranchers leaving Mato Grosso were in fact departing for farther north in anything but the abstract notions of both the farmers themselves and the conceptual ideologies of my research, I needed to pursue my research plan to its full extent. And after several weeks canvassing northern Mato Grosso I was now planning my first drive into Pará. The realization, however, had left me nervous. Driving north to Novo Progresso would be driving twelve hours northward on a notoriously decrepit roadway, one of which I was mostly unfamiliar.

And driving in the Amazon, I was quickly learning, was fraught with several unique challenges. To the south, it was dodging and weaving the double trailer grain trucks that flow towards the Atlantic coast. This was a lesson that I had quickly learned in my first week on the road, when me and my rented fiat hatchback skimmed dangerously close to our mortal limitations. One early attempt to pass, I recall, had caught me in the no man's land to the side of a double trailer grain truck with no escape and an oncoming Toyota Hilux racing toward me at over 100mph. I had misjudged how fast the pickup would be closing, and now I was sure to pay a steep price for the oversight. There was no chance to drop back, though I was nonetheless in the midst of endeavoring to do so, when I embraced the suddenly peaceful sensation of the coming pickup truck that would certainly lead to a rapid end and my encasement within a charred and contorted sarcophagus of steel and plastic, engineered by fiat. I was pleasantly surprised when the oncoming pickup managed to deftly maneuver itself onto the shoulder and safely passed to my left without harm.

Not that I would encounter many, if any, grain trucks farther north. The farther north you went, the sparser the traffic. In fact, the river of grain trucks would dry out completely just north of Sinop, where the roadside transforms from endless plots of commodity crops into pasture and forest. Still, the dry dusty feeder tracks off of BR-163 had made me realize that, even if free of the towering grain trucks, the lesser traveled roads held their own perils. The tiny communities that they connected, which may or may not include a functioning gasoline station, were widely dispersed, and were often separated by more than one or even two hours of driving. In between were deceptive and never mapped forks and turnoffs, rugged postholes, and crude wooden bridges. I would pass few, if any, other vehicles, and those that did fly by from the opposite direction served only to remind me of how isolated these roadways were.   Getting lost or developing a mechanical condition could be extremely dangerous and would likely entail an adventure spending a night, if not several, on the roadside. The road north to Novo Progresso would be more likely to resemble one of the ancillary offshoots of BR-163 than the paved highway farther south.

Several years previously when I was in Sinop I had actually traveled through much of northern Mato Grosso, and had arrived as far as the border with Pará. During that trip the pavement came to a halt 18km before the border, and the final stretch was a slow crawl through first a weave of construction and later, a riddled and rutted stretch of sand traps, bridges and packed soil. Now I would finally have the chance to not only return to Pará, but to complete the highway, or to stitch my 2007 trip from Santarém south to Novo Progresso with this one, to Novo Progresso from Cuiaba and Sinop. It was my Brazilian version of patching together the entirety of the Appalachian Trail, albeit a motorized one. When I made it to Novo Progresso, I would return to speak with Agamemnon and, with luck, would encounter ranchers who had arrived from the present day soybean regions of farther south.

To ease my nervousness over the 12 hour drive north on some of the most troublesome segments of the BR-163, I had invited another Ph.D. student working farther south to accompany me to Novo Progresso. From there she would book a bus ticket to continue her travel northward to Santarém, to complete the field work required for her dissertation. After a quick fill up we were on our way north, cruising over the lightly traveled asphalt north of Sinop. Early that afternoon we refilled again at Guarantã do Norte, the final outpost in northern Mato Grosso and last significant city before Santarém. With a full tank of gas and a prayer we motored out towards Pará, unsure of what lay ahead.

Shortly after leaving Guarantã the highway traverses what has, historically, been its most fearsome terrain, the sandy hillsides of Cachimbo. Yet even as we approached the GIS point that I had marked two years earlier to mark the last of the asphalt, the road was in a pristine condition. It wasn't until nearly the border with Pará that the pavement ran its course, forcing us to weave through a patrol of highway crews and heavy construction equipment, that our front tires touched the soft earth and once again commenced spitting out a wake of churning dust and exhaust.[28] Shortly thereafter the construction crews would also disappear and, with the exception of water crossings and several of the more precarious hillside locations that required advanced construction work, we were left to contemplate the region's withering solitude.

Resigned to the slow, steady grunt work of driving through Cachimbo, we were perplexed by the sudden resurgence of construction two hours later. Coming down the northern slope of the range we were greeted by a welcomed segment of pristine pavement, and what may have been the nicest road in Brazil, glistening with freshly set asphalt. The road took us downward to the valley leading to Castelo dos Sonhos, literally meaning your "Dream Castle," thirty miles ahead. For the time being, Castelo would need to serve as our temporary destination. In addition to the coming nightfall, we had learned that any further travel northward was going to be blocked by a landless workers' protest some 100km beyond Castelo. Evidently,

[28] Ten days later, on my return trip I learned from a passenger working on the project that 14 companies were working on paving the BR, at the cost of approximately 1million reals (600,000$US) per kilometer.

upon rumors that a ranch was poised to be expropriated for redistribution to occupiers somewhere else in Pará, another group of landless workers had moved in to occupy it for themselves. Loath to leave, they chose to make their voices heard by closing the only transportation corridor in the region.

After two days in Castelo my travel companion decided to catch a bus to Santarem. The bus company, we were told, would send transport from both direction and the drivers would swap passengers at the blockade. I had planned to stay in Castelo for another night to see if the road would be reopened. Later that evening, however, the owner of the posada where I was staying knocked on my door to say that a rumor had begun to percolate that the authorities had negotiated for a temporary opening of the highway, beginning at midnight. I departed the posada that evening by 9.30, expecting to arrive thirty minutes prior to the opening. The nighttime drive toward the blockade was solemn underneath the full canopy of the star filled heavens. And after a brief wait, sure enough, the blockade was opened and several dozen trucks illuminated the far side of the barrier, and then proceeded to roll forth in a roiling, dusty barrage of diesel exhaust and purring engines. Once those waiting from the north had passed, a path was opened to the line that had formed on our half of the barrier. It was now past midnight in one of the most remote areas of the Amazon and here I was caught in traffic, with horns blaring, lights shining, and engines purring. And Novo Progresso remained approximately one hundred kilometers, or about two hours' drive, to the north.

The nighttime drive of the previous hours had helped me to overcome many of my fears of driving in the dark; however, I was unprepared for driving through the blizzard of sand that would lay ahead. The sandy roads of the Amazon and the dust that they produce are tolerable, in part, because of the sparse level of traffic in the region. Typically, the dust settles shortly after a vehicle passes, and issues emerge only when two vehicles meet or one overtakes another, a comparatively rare occurrence in the region. However, in the present instance, more than three dozen pickups and large freight trucks were poised to sprint out this last segment before Novo Progresso, all in succession. I found myself gripping the wheel as if in a blizzard with near zero visibility, often able to follow only taillights as if in a dense fog. By three AM that morning I finally had arrived in Novo Progresso and pulled into the packed lot of one of the city's two hotels. No sign of smoke or the charred scent of forest clearing permeated the air.

Two days later I found myself again before Agamemnon, in the same seat where I was warned, not welcomed, four years before. The conversation, however, had come full circle. The producers' representative before me was welcoming. Some of our conversation resembled the implicit megalomania of our previous meeting (he had seen me that morning in the hotel and inquired into who I was at the desk). Yet it was also clear that, while his despising of NGOs had only been slightly abated, the realities facing Novo Progresso had changed. New controls on deforestation and land sales had redefined the region. An ambitious Zero Illegal Deforestation program had been implemented, to some success. The first rural titles were being issued to property owners who had documented rights to possession in the region for decades. IBAMA now had an outpost firmly established in the town itself. And both the creation of the road and the influx of laborers responsible for its creation were buoying the city's economy. Elsewhere in the city, a group of ranch owners were seeking to bring international NGO's directly into the region to assist with landowners' compliance with the new federal laws for landowners in the region, and to help fund regularization of property, per the CAR and LAR requirements handed down by the federal government. And, literally, the smoke had lifted from Novo Progresso. The capitalist margin had finally reached Novo Progresso.

Here was a new Novo Progresso, a city that was once one of Brazil's most remote and chaotic frontier towns, now under the guise of national politicians, international commodity traders, environmental watch groups, soybean companies, and beef packing plants. The road project, arguably being completed at the behest of the emerging soybean lobby in Mato Grosso, was resulting in higher land prices and new interest in the region. The benefits were likely to come. Yet for some, they would come at the cost. They would come with the ceding of much of the municipio to newly-created protected regions. They would come with the indefinite halting of the enormous new packing plant that now idles in a partial stage of completion in Castelo dos Sonhos, awaiting an undefined environmental compromise that may never be arranged. And near the Novo Progresso airfield, the only farmer who continues planting soybeans in the district, whose newly cleared fields were featured in photos distributed worldwide by Greenpeace, was no longer able to sell his soybeans to Cargill in Santarém. After Cargill signed an agreement with environmental NGOS to certify their soybeans as "responsible" this farmer, of apparently modest means, has since been selling his soybeans in Santarem to local purchasers, where the product largely finds its way into the local food stream as swine or broilers. The extension of BR-163, completed at the behest of the soybean farmers of Mato Grosso, was going to be off limits to those wishing to plant soybeans along the road itself.

Novo Progresso, and indeed, the producers association that had once driven much of the city's politics, had also changed its tone. The defiant cry against the world had been replaced with a cry for examination. Stay away was replaced with *stay here and understand*; understand the protections that we have in place, the realities that we live in, and the ambiguity between legal and illegal. The same cry had been rung out farther south, in Mato Grosso, where soybean producers that had once faced the unwanted lashing of the global environmental community now had switched their tack and sought to show the world what they have accomplished. Come and see; all that we have is pride, pride that we have started with so little, and erected cities, planted gardens of grain, and have founded universities for our children. Come and see. Would the long time juntas of Novo Progresso also want to open their windows to the world? Naturally, not exactly. However, the sands that were shifting below their feet (or hooves) were unlikely to leave any choice in the matter.

As my conversation with Agamemnon was coming to a close it dawned on me how much the road had revolutionized Novo Progresso. The irony, however, was that this very project, one which had long been clamored for, was being built not for the inhabitants of these regions, but rather at the behest of the growing soybean lobby farther south. In what was perhaps the grandest of bargains the project was only pushed forward with the simultaneous creation of the several new protected areas, effectively closing this region off from some of its potential in order to realize greater profits and new opportunities farther south in Mato Grosso. I mentioned this to my partner in conversation, and suggested that perhaps his anger towards the NGOs was misdirected? Perhaps the NGOs themselves were little more than tools in this broader, complex system of politics and influence, directed more by interests of economic opportunity than the environment. On this point, we could agree. And then I promised to come back.

APPENDIX

Table A.1 Stage1 Regressing soy effect on the exogenous and instrumental variables				
	Logged Unpartitioned	**Unlogged Unpartitioned**	**Logged Partitioned**	**Logged Partitioned**
Nobs	1336	1727	1039	1345
Dep. Var: $W_i^T S_{i,t}$				
$W_i^N D_{i,t-1}$	0.35 (0.003 ***	0 .01 (0.00)**	0.03 (0.00)***	0.00 (0.00)
$W_i^N C_{i,t-1}$	-0.00 (0.00)	0.02 (0.01)***	-0.00 (.00)	0.016 (0.00)***
P_{t-1}^P	0.04 (0.01)***	0.00 (.00)***	0.021 (0.01)**	0.00 (0.00)
$W_i^N Upop_{i,t-1}$	0.00 (0.00)	3.43 (0.37)***	-0.00 (0.00)	2.61 (0.41)***
$W_i^N Rpop_{i,t-1}$	-0.01 (0.02)	1.35 (2.00)	-0.03 (0.02)	2.42 (1.46)*
Year 1				
Year 2	-0.01 (0.01)	6.88 (1.01)***	-0.06 (0.01)***	0.38 (2.08)
Year 3	0.31 (0.01)***	23.58 (1.25)***	0.25 (0.01)***	13.40 (2.44)***
Year 4				-2.90 (2.82)
Year 5	-1.18 (0.01)***	-32.78 (1.08)***	-1.19 (0.01)***	-32.18 (2.48)***
Year 6	--1.52 (0. 01)***	-19.39 (2.19)***	-1.49 (0.02)***	-24.90 (1.26) ***
Year 7	-.39 (0.02) ***	10.59 (2.77)***	-0.45 (0.02)***	
Year 8	-.75 (0.01) ***	-11.52 (1.82)***	-0.73 (0.01)***	-16.22 (1.33)***
Year 9	-.21 (0.01) ***	1.59 (1.52)	-0.19 (0 .01) ***	-3.01 (1.68) *
Cons	3.43 (0.06)***	10.50 (3.68)**	3.53 (0.06) ***	20.50 (1.37) ***

Table A.2 Stage2 Regressing deforestation on all explanatory variables plus the residuals from stage 1				
	Logged Unpartitioned	**Unlogged Unpartitioned**	**Logged Partitioned**	**Unlogged Partitioned**
Nobs	1336	1727	1039	1345
Dep. Var: Deforestation				
$W_i^N D_{i,t-1}$	0.49 (0.12)***	0.04 (0.02)***	0 .35 (0.22)*	0.02 (0.02)
$W_i^N C_{i,t-1}$	0.06 (0.03) *	-0.06 (0.05)	0.09 (0 .04) ***	-0.08 (0.05)*
$W_i^T S_{i,t}$	2.31 (0.32)***	1.29 (0.29)***	1.01 (0.49)	1.81 (0.34)***
P_{t-1}^P	0.37 (0 .17)*	-0.01 (.01)	0.14 (0.19) **	-0.01 (0.01)
Year 1				
Year 2	-0.46 (1.01)	50.75 (17.24)**	-0.59 (9.83)	19.98 (15.90)
Year 3			-0.93 (11.97)	
Year 4	-0.72 (0.95)	41.26 (21.76)*	-0.83 (10.27)	5.84 (14.38)
Year 5	-3.67 (4.61)	31.26 (15.49)	-0.41 (2.08)	-2.65 (36.66)
Year 6	-4.23 5.73	-5.66 (3.87)		2.04 (39.41)
Year 7	-1.85 (2.27)	0.92 (8.65)	-0.93 (7.23)	-18.51 (24.64)
Year 8	-3.14 (3.34)	-20.61 (7.11)***	-1.20 (5.21)	-29.95 (31.34)
Year 9	-1.91 (1.67)	-18.67 (12.66)	-1.37 (8.96)	-46.46 (21.42)
Residuals from Stage 1	-4.31 (3.08)	-1.28 (0.31)***	-0.13 (6.85)	-0.73 (0.78)
Cons	6.39 (11.56)	41.67 (12.45)***	-2.11 (13.89)	45.43 (44.62)
F test (residuals)	(1, 1084) = 1.96	(1, 240) = 17.09	(1, 813) = 0.00	(1, 1115) = 0.88
Prob > F	0.1620	0.0000	0.9846	0.3485

General Maps of Brazil

Figure A1.1 *The Six Biomes of Brazil*

Figure A1.2
Brazilian States

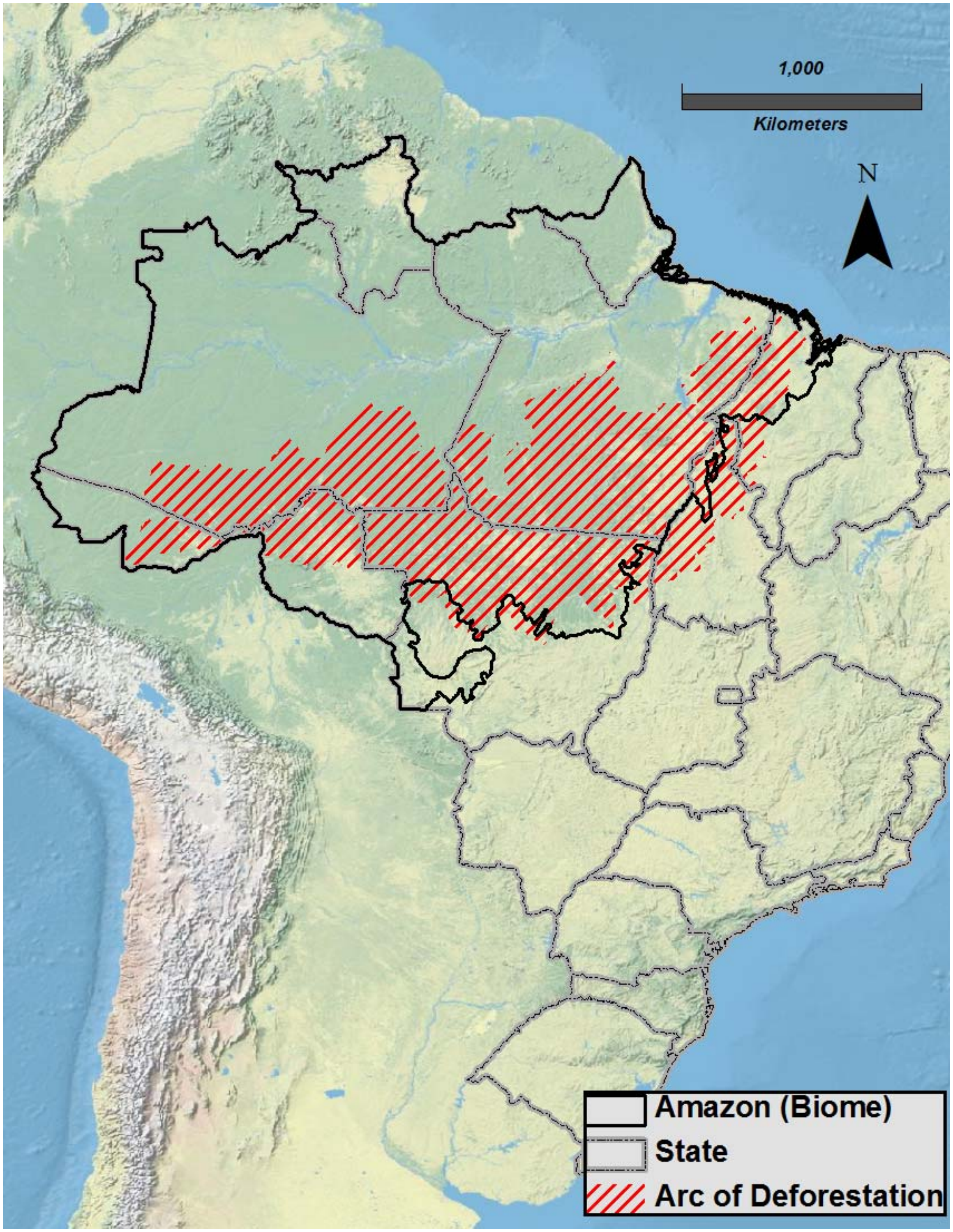

Figure A1.3
The Arc of Deforestation

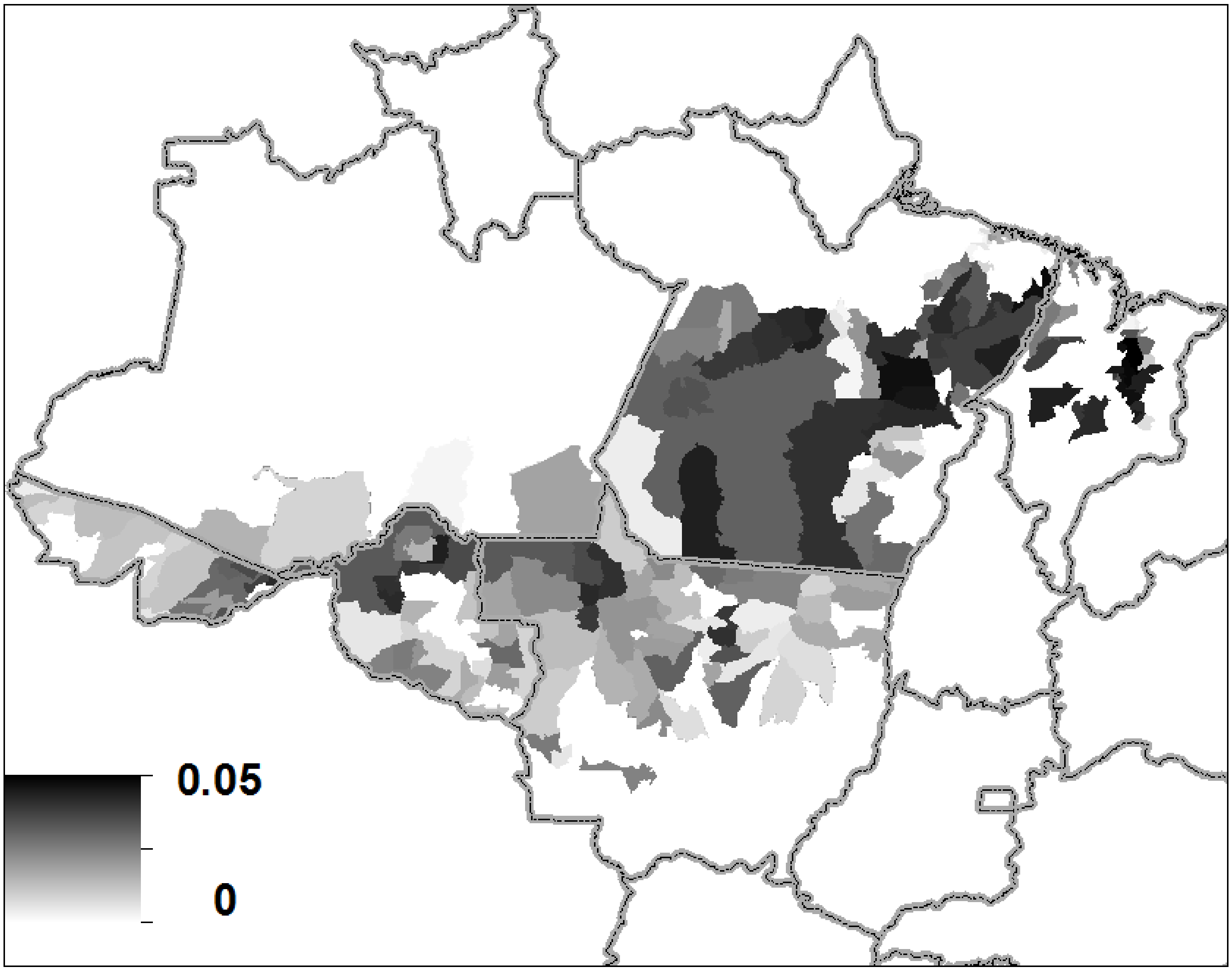

Figure A2.1
Percent deforestation (total deforestation, normalized by area), 2004

Questionnaire

Projeto do movimento e expansão da produção Agropecuária na Região Cuiabá-Santarém
Michigan State University
Department of Agricultural, Food, and Resource Economics; Department of Geography

Nome ________________________________Posição ou
cupação_____________________________
Data______________________________ Município,
Localização_____________________________

Recently Arrived Farmer Survey

1. **Year of Arrival __________________ Year of Purchase__________________**

2. **What was your previous occupation?____**
____
How long were you there?
____

3. **If previously engaged in farming, how large was your previous operation? __________**
   a. **Planted Area______________________ Forest Reserve _________________________**
   b. **Pasture Area ______________________Other ________________________**

4. **How large is your present operation?**
   c. **Planted Area______________________ Forest Reserve _________________________**
   d. **Pasture Area ______________________Other ________________________**

5. **Do you have land allocated for other production purposes (e.g., pasture, reserva)? If so, how much? ____**
1. Use________________ Area__________ 2. Use____________ Area__________
3. Use________________ Area__________ 4. Use____________ Area__________

6. **Why did you decide to purchase land here in this *municipio*? Please Rank.**
<<<<<<1 = least important;;;; 5 = most important>>>>>

Price	**1**	**2**	**3**	**4**	**5**
Contacts	**1**	**2**	**3**	**4**	**5**
Soil Quality	**1**	**2**	**3**	**4**	**5**

Proximity to Roads	**1**	**2**	**3**	**4**	**5**
Rainfall	**1**	**2**	**3**	**4**	**5**
Clear Titles	**1**	**2**	**3**	**4**	**5**
Producers' Organizations	**1**	**2**	**3**	**4**	**5**
Other________________	**1**	**2**	**3**	**4**	**5**

7. **(If known) why did the previous owner of your land sell their property?**
____
____

8. **(If known) What did the former owner of your ranch do after the land was sold?**
e. Location ___________________________
f. Professão ___________________________

9. **After your arrival, did the land use change? If so, how? ___________________**
____
____
____
____

10. **How old were you when you arrived?** _________________

11. **How old was the previous landowner?** 0-20 20-30 30-40 40-50 50+ (or Age______)

12. **How many years of education have you had? __________________**

13. **Highest level achieved:** **None Elem HS Univ**

14. **If you were to receive an offer for your land that was high enough for you to sell it, would you____________**
a. Move and become a rancher ________________
b. Retire or stop farming________________________
c. Move and farm (location) ____________________

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