

The Post-frontier: Land use and social change in the Brazilian Amazon (1992 – 2002)

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Dedicated to my nieces Valentina Anouk and Gaelle Luciana, both born during the last stages of the writing of this dissertation, in the hope that they find as much passion and inspiration in life to guide them through the fulfillment of their own dreams as I do with mine... and to my grandfather Manuel Sarria and grandmother Consuelo Garcia, who passed away during my days in Blacksburg, from whom I learned to live life passionately and to follow my dreams...

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THE POST-FRONTIER: LAND USE AND SOCIAL CHANGE IN THE BRAZILIAN AMAZON (1992 – 2002)

Percy Manuel Summers

ABSTRACT

Deforestation of tropical forests is one of the most pressing environmental problems of the twenty-first century, leading to the loss of environmental services such as climate regulation and biodiversity. The expansion of the agricultural frontier by small landholder farmers continues to be one of the major drivers of land use change in the Amazon region. Much of the recent research in the Brazilian Amazon has been focused on modeling their behavior in order to prescribe policies that can curb current deforestation rates and promote more sustainable land use practices. The availability of more sophisticated remote sensing and economic modeling tools has led to the proliferation of agricultural household level models that attempt to explain land use change processes at the farm level. This dissertation tests the household life cycle theory in one of the oldest colonization fronts in the Brazilian Amazon: Rondônia, now a post-frontier.

The study examines household and farm level changes over time for specific aspects of the frontier process that can be tested using the household life cycle theory. This study introduces important additions to the life cycle theory in order to consider the more dynamic and complex set of factors that characterize modern frontier processes. Specifically the study examines: (1) property fragmentation and expansion processes, (2) property ownership, turnover and change, and (3) land use change processes at the property level. These are linked to changes in the social and economic features of the smallholder farmer as it moves along its life cycle. The central hypothesis is that these changes in property and land use dynamics can be explained by the corresponding changes in the life cycle of the household as the frontier evolves over time into a post-frontier.

It was found that the household life cycle theory did not adequately explain land use change processes over time. As the frontier evolved into the modern post-frontier, the labor and drudgery constraints associated with the initial frontier processes, as exemplified in the household life cycle theory, became less relevant. The Sauerian concept of cultural successions and the concept of scale from hierarchical ecology are used in order to explain the apparent inconsistencies found between the household life cycle theory and land use change processes over time and at different scales of analysis. The household life cycle theory is a useful theoretical framework from which to examine the effects of household level factors on land use; however, this must be embedded within concepts of time and scale that determine their differentiated impact and behavior.

Existing plans to expand road infrastructure into the Amazon region will open-up previously inaccessible rainforest regions to agricultural frontier expansion at a scale unprecedented since the mid-eighties. Findings from this study reveal that policies based on household life cycle postulates will have limited impacts in reducing deforestation rates and promoting sustainable land use practices. Appropriate accounting of the social and environmental costs of future infrastructure development projects should consider associated frontier agricultural expansion costs to discourage further deforestation.

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CHAPTER 1

INTRODUCTION

Ordem e Progresso [Order and Progress]
(Modernist inscription on the Brazilian flag)

Brazil almost overnight became the environmental villain when the ecopolitics of the world system changed in the mid-1980s. (Barbosa 2000)

The record of the Transamazon highway indicated that the “frontier solution” of demographic displacement served more as a diversion than as an effective policy response to problems of underdevelopment in Brazil’s older rural communities. The utopian notion that entire settlement systems, inspired in central place theory, could be planned and implanted in wholesale in the rainforest landscape proved to be ridiculously naïve. (Browder and Godfrey 1997)

...to settle a people without land in a land without people... (Brazilian President General Medici 1969)

Introduction

From 1965 to 1990, the Brazilian Amazon was the setting of a massive influx of migrants from the most populated regions of the country in what has been described as the opening of the last great frontier (Foweraker 1981; Pomper Mayer 1984; Smith 1982; Schmink and Wood 1984; Browder 1988). The expansion of settlers into the Amazon region was associated with highly publicized environmental degradation and social unrest (Millikan 1988; Schmink and Wood 1992; Fox and Brown 1998). On one hand, environmentalists and ecologists became concerned about the rate and extent to which tropical forests were being replaced by what was considered unsustainable land use practices, especially cattle ranching and widespread slash and burn agriculture (Browder 1988; Fearnside 1993; Myers 1993). On the other, social scientists revealed the magnitude of violence associated with state-sponsored colonization schemes, including the displacement and extermination of traditional peoples (Hecht and Cockburn 1989; Schmink and Wood 1992). The scholarly attention focused on Amazonia led to a vibrant discourse on frontier colonization, speculating about the future of the Amazonian rainforest, its conservation and the acute social problems associated with the development

model that had been adopted. These have been called “frontier theories”, a term inherited from Frederick Jackson Turner’s influential essay on the importance of North American westward expansion in the development of American democratic institutions and cultural identity (Turner [1893]1961). The Brazilian versions have been radically reconfigured by a range of more recent theoretical schools within the social sciences (e.g., peasant economics, dependency theories, political ecology, Chayanovian household life cycles).

One of the most influential and robust frontier theories has been the household life-cycle theory (e.g., Moran 1989; Pichon 1996; Vosti 1992; Walker et al. 2002; Perz 2002). This theory conceptualizes the frontier as passing through a series of stages that correspond to the stages in the lifecycle of the initial settlers. As households age, they adapt livelihood and land use strategies to their demands and labor capabilities. Initially, when the family arrives and is young, subsistence crops predominate. As children mature and labor constraints are relaxed, families produce above consumption levels and engage in cash crops and cattle. The cycle ends when the soil is exhausted and the land is no longer able to maintain the multiple families of the sons and daughters of the original settlers. This younger generation is forced to move further along the frontier in search of its own lot of land starting the cycle once again. This image of the Amazonian frontier has permeated popular views about Amazonian colonization (Myers 1980; Martins 1981; Pinto 1991; Time 1988; National Geographic 1988; Cowell 1991). More recently it has become an inherent component in modeling land use change efforts in Amazonia (Evans 2001; Walker et al. 2002; Wood and Porro 2003). Its assumptions underscore proposed policies aimed at curbing deforestation rates in tropical forested regions¹.

The household life cycle theory originated in the late 18th century, by Alexander Chayanov, to explain land use practices of peasants in rural Russia in a context of land abundance and labor scarcity. This is similar to the one that characterizes Amazonia today. However, markets for agricultural products were almost non-existent; therefore the thesis specified small landholder land use strategies were dictated by the marginal curves

¹ For example, in a conceptual framework Reardon and Vosti (1995) created to explain the links between poverty and the environment, they claim small landholders in the Amazon are constrained by soil nutrients, labor and cash to meet food production. In order to break this cycle, the poor must shift from a reliance on biophysical processes to markets. Ozorio de Almeida and Campari (1995) designed their research questions to find household level factors that can later inform policy recommendations to reduce farmer turnover rates and reach farm size stability.

of drudgery, adult labor availability, and subsistence needs, all of which in turn changed in relation to the life cycle stages of the household. Recent models adapted for Amazonia have included markets for agricultural products, specifying however that labor availability and subsistence requirements are still determinant factors in land use allocation. Based on recent literature and field observations I proposed modifications to the household life cycle theory to include different pathways at the end of the life cycle that explain changes not only on land use strategies but also in the capacity of a household to expand their landholdings, or, alternatively, their need to fragment their property or sell-out.

While the household life cycle theory is important for understanding land use change at the property level, as the frontier becomes articulated to the wider regional and global economy other exogenous factors might become increasingly important. This seems to be the case of the modern Brazilian Amazonian landscape, most of which can be described as moving into a post frontier. This post frontier setting is characterized by the growing influence of urbanized centers within the Amazon region which in turn have created a rising demand for agricultural products and land as investment opportunities. However, regional forces are not the only new drivers of land use change. Global markets for beef and biofuels from agricultural crops are also having an increasing influence over land use decision patterns in the properties of small landholders. For example, since the year 2000 Brazil has become a net exporter of beef and the demand for land to increase cattle production is coming from the fringes of frontier regions as Rondônia. The prospects of large infrastructural development projects under the “Initiative for integration of regional infrastructure in south America” (IIRSA) umbrella (continent-wide transportation, energy and communications investments) might still have a larger impact over the Amazon in the near future, accelerating many of the current processes of intraregional migration and economic articulation with other regional and global markets with important repercussions over the landscape.

This dissertation critically re-examines the household life-cycle theory by determining if the trends and patterns of land use found in the field correspond to those predicted by this theory. It systematically tests the relevance of the household life-cycle frontier theory in predicting land use and social change under the highly dynamic

regional context of the southwestern Brazilian Amazon. It accomplishes this by analyzing several key issues from a panelized data base derived from a household-level survey of 240 rural properties in 1992 and revisited in 2002. It specifically examines: (1) property fragmentation and expansion processes, (2) property ownership, turnover and change, and (3) land use and land cover change processes at the property level. The overriding hypothesis is that these changes in property and land use dynamics can be explained by the corresponding changes in the life cycle of the household as the frontier evolves over time. The changing social and political context of the Brazilian Amazon frontier requires revisiting the life-cycle frontier theory for its relevance to our current understanding of frontier processes. As most of Amazonia gives way to a post frontier scenario, it becomes increasingly important to reexamine this theory in light of the current landscape of modern Amazon.

The study is also relevant and timely given the recent emerging trends of endogenous migration patterns to new frontier regions (e.g. southern Acre, northern Mato Grosso, and southern Amazonas) and a resurgence of Brazil's interest in expanding the existing road network. This would make accessible tens of thousands of square kilometers of previously undisturbed forests, creating conditions for migration patterns and deforestation levels not experienced since the early 1980s (Carvalho et al. 2001; 2002; Laurence et al. 2001; Andersen et al. 2003; Killeen 2008). Only by understanding the nature and dimensions of these frontier processes can an effective mitigation strategy be designed to control future deforestation levels.

My findings suggest a very different post-frontier scenario has developed in the Brazilian Amazon than the one specified in the household life cycle theory. This is even after considering important modifications to the theory in order to take into account new trends as specified in recent literature on Amazonian frontiers. The existing social and land use patterns that characterize the modern Amazonian landscape are more in tune with an increasing influence of global markets in land use decision-making processes than to the aging life cycle of the household. The findings have important potential repercussions over policies aimed at controlling the opening of future frontier areas, managing existing post-frontier regions and for planning strategies for promoting economic development and conservation of tropical forested landscapes in general.

This dissertation contains seven chapters. Following this introduction, chapter 2 is a critical review of frontier theories. It discusses the assumptions and epistemological frameworks that shape these frontier theories and their place within the broader realm of the social sciences. It also explores how different theoretical schools envision the post-frontier setting of Amazonia. This led to revisiting the household life cycle theory to include some modifications in order to adapt it to the new context of a globalized economy, following the transition from an active government-sponsored development to an increasingly market driven milieu. Chapter 3 addresses field work, research questions, hypotheses and methods. Chapter 4 contextualizes the thesis by reviewing the socioeconomic and environmental history of the State of Rondônia. Chapters 5 and 6 comprise the major part of the dissertation and test whether the household life cycle theory can explain the trends in property and land use dynamics that characterize the present Rondônian landscape. Chapter 5 examines property dynamics, specifically major trends in the size of the properties (fragmentation, expansion and consolidation processes) and in the ownership of these properties (farmer turnover rates or farmer stability), and testing whether the household life cycle factors can explain these changes. Preliminary analysis of the data set showed that, unlike conventional theories that predict frontier consolidation with time (e.g. Moran 1989), 25 years after the initial colonization period, property ownership and size changes are still highly dynamic, suggesting a more critical look at the factors that drive these changes and the consequences they have over land use change processes. Chapter 6 traces the evolution of natural resource use in the landscape as it pertains to land use practices such as perennial crop planting, annual crop planting, pasture development for cattle and land fallowing (secondary growth). It specifically looks at household level factors that can inform policy makers on how to promote more sustainable land use practices in Amazonia. Chapter 7, the concluding chapter, refers to the most salient findings of each chapter and how they compare to the predictions emanating from the household life cycle. It attempts to organize and integrate these analytical findings into an explanation of the closing frontier that is contextually local to the Rondônian frontier but that can help understand other frontier processes elsewhere and in the future. Furthermore it discusses if the modifications I proposed earlier to adjust the household life cycle theory to emerging trends, appropriately capture

the rising complexity of the post frontier landscape. Finally implications of these findings for economic and agricultural development, rainforest conservation and regional planning will be discussed. Directions for future research are also identified.

Background

This dissertation is part of a larger project funded by the National Science Foundation². The project identifies factors at the household level that explain changes in land cover and land use strategies among smallholder farmers in the Brazilian Amazon. This larger project, co-directed by Dr. John O. Browder, Dr. Robert T. Walker, and Dr. Randolph H. Wynne, relies on an extensive longitudinal panel data set of 240 households in three representative settlement areas of the Southwestern Brazilian state of Rondônia. The panel group of smallholder farmers was first surveyed in 1992. A second survey including the same questions was administered in 2002. Survey data from 1992 and 2002 includes detailed description of land cover and land use as well as demographic and socioeconomic information about the household. The survey data were integrated with remote sensing analyses of Landsat satellite images for each study site that identifies each household's boundaries and land cover within each property for the ten year study period (1992-2002). A subgroup of properties was revisited in 2003 for in-depth interviews to reconstruct the land use history of the property during the last ten years and the reasons for the different land use decisions. However, while the dissertation builds from these data sets, the analysis of the household life cycle theory relies specifically on the richness of the 1992 and 2002 survey panel data set. Furthermore, the dissertation examines key questions that have emerged from preliminary analysis of the data and uses these too critically revisit the household life-cycle frontier theory in light of contextual changes in the political and socioeconomic context of the Amazon region.

The research for this dissertation built on my long-standing interest in Amazonia and ten years experience working in this region prior to the two years of research for this dissertation. While the focus here is on the southwestern Brazilian Amazon, the questions

² NSF project: John O. Browder, Robert T. Walker, and Randolph H. Wynne, Patterns and processes of landscape change in the Brazilian Amazon: a longitudinal comparative analysis of smallholder land use decision-making, NSP grant #BCS-0136965.

it attempts to answer and the particular historical and environmental context of this region are relevant in the other seven countries encompassing the Amazon basin as well as other tropical forested regions throughout the world. It combines a pragmatic pursuit of alternative solutions in the region, using my background as a tropical forester and ecologist, with an interest in the broader concerns contemplated in social science theories (e.g. causes of underdevelopment). Although my interest in the region were initially focused on the conservation of its biodiversity, I agree with scholars who identify the limits of the conservationist agenda to be its reliance on a scientific diagnosis as opposed to the social and political processes that overshadow any simplistic solution to the Amazonian question. In this dissertation I have sought to combine methodologies that can be applied with an interest in understanding the broader issues behind the acute environmental and social problems the Amazon region presently faces.

Contributions

The main contribution of this dissertation is to demonstrate that the capacity of the household life cycle theory to explain the social and land use characteristics of the emerging post frontier Amazonian landscape has been overstated. The expansion of the frontier into the rainforest and its associated deforestation and social conflicts produced an extensive literature on frontier colonization (Moran 1984, Schmink and Wood 1984, Henriques 1988, Browder 1988, Lena and Oliveira 1991, Ozorio de Almeida 1992, Pichon 1996). Based mostly on theoretical approaches from political ecology, frontier stages and on the household life cycle theory, this literature drew a very pessimistic outlook of the Amazon frontier in the future, characterized by the ecological deterioration of the landscape and the expansion of capitalism as the dominant force driving land use and social relations of production. This dissertation has empirically tested how the present post-frontier in the region compares with that predicted by the household life cycle theory. The study corroborates previous observations which indicated that the modern Brazilian Amazon is quite distinct from the one that had been envisioned by frontier theories despite their consistent influence in current perceptions of the Amazon. It did this by analytically testing and challenging perceived notions of the Amazonian

frontier based on the household life cycle theory. The changing context of the Brazilian Amazon in an age of increasing globalization required that these theories be revisited and updated.

Conventional frontier theories also need to be revisited in light of the wide range of emerging changes in the Amazon region, such as the proposed large-scale road expansion and infrastructure development planning scheme under the title of the “Initiative for integration of regional infrastructure in south America” (IIRSA)³. During the recent decades, frontier expansion into the region has been limited by the Brazilian state’s hesitation in expanding the road network after the onslaught of negative publicity it endured during the mid and late eighties in relation to state sponsored colonization. This is no longer the case. The proposed project would link the core region of the Amazon to the existing road network and would almost double the amount of forest area susceptible to frontier expansion from 16% to 28% of the Brazilian Amazon basin (Nepstad et al. 2001; Carvalho et al. 2002). Although the social and environmental costs of road expansion have been widely documented, the long-term sustainability of such endeavors still relies on widely held assumptions that are embedded within economic growth paradigms of conventional development models⁴. This dissertation, using a panel data group and studying the land use practices, survival and sustainability of small farmers over the life cycle of the original settlers fills the gap in our knowledge about previously forested regions of the Amazon. This study is of particular interest to Amazonian scholars working to further our understanding of the underlying characteristics and outcomes of agricultural frontier expansion and for policy makers interested in the long-term outcomes of predominant development models based on agricultural expansion and small landholders. The dissertation’s analysis of the factors that guide these processes are of interest to policy makers and analysts interested in

³ Roads continue to be the most important predictor of deforestation and frontier expansion in tropical forested regions (see review in Angelsen and Kaimowitz 1998). IIRSA is a intergovernmental economic development plan financed by the InterAmerican Bank that in Brazil alone would increase the existing road network by more than 6200 km. It would provide all-weather road access to the core region of the Amazon for the first time, especially the section that cuts across the Santarem-Cuiaba and the Humaita-Madeira sections, which will go through 1800 km of currently inaccessible forests.

⁴ However, recent literature based on econometric analyses of the costs and benefits of road expansion partially support roads as economically beneficial in the long-term for rural landholders (Andersen et al. 2002).

promoting sustainable land use outcomes and creating alternatives to mainstream development programs.

CHAPTER 2

FRONTIER THEORIES: CONCEPTUAL FRAMEWORKS

The frontier: definitions and conceptualization

The frontier evokes images of vast expanses of wilderness, pristine forests, abundant game, and endless extensions of land. It offers unlimited opportunities for those willing to settle at the edge of the “civilized” world. It is associated with feelings of hope and of future prosperity for those ready to “conquer” and “domesticate” it.

The frontiersman captured the imagination of the American public and of scholars like Frederick Jackson Turner, who saw in the frontier the birth of the American cultural identity and its institutions (Turner [1893] 1961). The Western frontier with its lure of land and freedom provided the ideal environment for developing the traits cherished by the American people; a nation settled by immigrants, many escaping from the religious persecution and economic oppression they had suffered in Europe. Thus, in the United States, the frontier became synonymous with opportunity for thousands of landless European immigrants who colonized the extensive prairies and forests of the American West. There, in a changing new frontier environment class distinctions disappeared, social and political equality were demanded instead and a new spirit of individualism and nationalism was born. Although the frontier in the United States closed more than a century ago, the myth of the frontier persists. Frontier images and expectations are said to be deeply ingrained in the American consciousness and still expressed in the restlessness to conquer new frontiers, from space exploration to the expansion of American values and institutions into other cultures (Williams 1969; Hennessy 1978) as well as in modern conceptualizations of nature and wilderness (Cronon 1995; Nash 2001).

A century later, Brazilian politicians and military leaders found fertile ground to feed the frontier myth to its millions of landless and hungry peasants⁵. The Amazonian frontier was officially opened in 1969 by the military regime with massive public investment, populist publicity, a strong nationalistic rhetoric and blind modernist faith in progress and development⁶. The discourse used during this period to justify the colonization of the Amazon revered pioneering and frontier colonization along heroic lines. Amazon frontier colonization was framed, although implicitly, in a Turnerian sense, claiming it would consolidate Brazil's geopolitical power in the region while helping to address social needs and integrating this "land without people" to the rest of the nation (Barbosa 2000). Today, the Brazilian frontier presents a different image from the one that characterized the United States frontier of a century earlier: immense forests and trees falling to the chainsaw of the itinerant agriculturalists, smallholder farmers constantly being displaced by loggers and cattle ranchers, growing wealth disparities, multinational corporate agribusiness interests taking over the most productive frontier lands, activists and social workers murdered in complicity with state officials and the abandonment of the farm as soils and watersheds can no longer sustain continuous agricultural production. The image of the Brazilian frontier ends with peasant farmers moving on to new frontier regions or gathering in the region's rapidly growing metropolitan shantytowns and leaving behind a landscape of degraded pastures and a demographic vacuum⁷. While the validity of this perspective has been questioned numerous times (Cleary 1993; Browder and Godfrey 1997), the imagery it evokes has been pervasive and persuasive (Barbosa 2000).

Consequently, in Brazil, the frontier loses its mythical force and is replaced by the voices of countless smallholder farmers and indigenous peoples who call for justice and

⁵ Agricultural colonists in the Amazon frontier can be considered "peasants". According to Ellis (1993) peasants are "households which derive their livelihoods mainly from agriculture, utilize mainly family labor in farm production and are characterized by partial engagement in input and output markets that are often imperfect or incomplete" (Ellis 1993: 13).

⁶ An historical analysis and review of the phases of development in the Brazilian Amazon is presented in Chapter 4.

⁷ Images of the Brazilian Amazon frontier are based on a collection of popular books, newspapers, journals and films reviewed—these include Lucio Flavio Pinto's series of newspaper articles written during the 1980s and collected in *Amazonia: a fronteira do caos* (1991); Edilson Martins' *Amazonia a ultima fronteira: a saga dos oprimidos, as multinacionais e a iminencia de um deserto* (1981); Planet of the Year, *Time* (1989); the December 1988 National Geographic Magazine issue on tropical deforestation; and Adrian Cowell and M. Kirk's PBS Frontline documentary "The Decade of Destruction" (1990)

land in their plight to survive. Why is the Amazonian frontier, with its vast land and forest resources not able to fulfill the frontier myth? To answer this question it is helpful to first examine how the frontier has been conceptualized, since this has informed policy makers in promoting the colonization of frontier zones and has framed researchers' ideas and theories about the frontier. Furthermore, it is the modern concept of the frontier that frames the images that guide the public into understanding how they perceive the frontier, from the migrants to the readers of National Geographic or Time. Although the concept of the frontier is readily recognized, it eludes precise definition; the concept of the frontier has multiple meanings, almost as diverse as the vast literature surrounding it. However, certain features of the frontier cross theoretical boundaries, allowing one to explore the concept in a broad sense. In the rest of this section I review the evolution of the concept as it has been applied in the Brazilian Amazon.

One of the predominant conceptualizations of the Brazilian Amazonian frontier, despite its numerous variants, comes from the political ecology literature, and can be summarized as “a peripheral region increasingly engulfed by capitalist influences” (Cleary 1993). This view claims a homogenization of the economic and social relations of production with capitalism ending up as the driving force of change (Martins 1975; Ianni 1979; Foweraker 1981). Consequently, early frontier studies carry an evolutionary bias in describing the frontier as moving through transitional phases towards a fully integrated and urbanized “closed” state. Related, but emphasizing the environmental aspects of the frontier cycle, other studies used the concept of frontier development to predict the eventual demise of the smallholder farmer as soil nutrients are depleted over time and the farm is no longer able to sustain itself (Henkel 1982; Moran 1984; 1989; Thiele 1993). These earlier studies of the Amazonian frontier permeate modern views of the frontier and how it is conceptualized despite how different the post-frontier presently appears.

Lena and Oliveira (1992) provide one of the most comprehensive reviews of the frontier concept for the Amazon region. They wrap up their review with their own conceptualization, claiming that the frontier is defined by the spatial concentration of economic activities that expand into a region where they were previously absent or poorly represented. They identify a series of characteristics that must be present for a region to

be conceptualized as a frontier. First, it involves socio-economic integration of spaces that were previously under-populated, and whose inhabitants do not necessarily belong to the same culture, or economic structure from the one that characterizes the rest of the country. The concept also implies a notion of scale and degree of socioeconomic integration to the rest of the nation. The simple installation of mineral-extraction enclaves or the exploration of local labor through systems of *aviamento*⁸ is not sufficient. It implies the permanent dislocation of populations to participate in the development of new activities in the region. If exclusively local populations participated in such new activities, the appropriate term for it would be local development, not frontier expansion. The external origin of economic agents, as well as the cultural, economic and social dislocation processes are intrinsic to the development of the frontier and explain the deep rupture and trauma often associated with displaced populations as well as the internal conflicts that arise between newcomers and the existing populations.

Browder and Godfrey (1997) present another review of the frontier concept, identifying five criteria used to define the term in practice: demographic, political, economic, social, and cultural. Demographically, the frontier is characterized by low population densities, high population growth rates, in-migration and the unstable appearance of boomtowns and ghost towns. Politically, it bears the footprint of the institutions that opened it (e.g., state sponsored settlement program versus mining enterprises, agrarian colonization agencies). Economically, markets for basic commodities characterize the social and economic organization of the frontier space (e.g., agricultural versus extractive frontier). Socially, the predominant social group or mode of production defines the frontier, whereby small farmers might dominate “agrarian frontiers”, “corporate frontiers” might be dominated by large ranchers or agribusiness enterprises. Finally, frontiers are culturally distinct depending on the type of interaction experienced by external and local cultures (e.g., smallholder colonists and indigenous populations).

⁸ *Aviamento* refers to a specific type of economic system of exchange, whereby extractivists are paid for their work with market products not found in the region by buyers that serve as intermediaries. The market products are usually overpriced and the system usually leaves the extractivists in perpetual debt. This economic system was well established in the interior of the Amazon, especially during the rubber boom periods, but also for gold mining, brazil-nut extraction, logging and other forest products.

Browder and Godfrey (1997) critically review the application of the frontier concepts to the Amazonian context, questioning the validity of some of their embedded assumptions, particularly its evolutionary bias and assumed movement toward a “closed” state. They propose, instead, conceptualizing the frontier as a sociospatial continuum, characterized by the coexistence of a diversity of socioeconomic groups, whose interaction, mediated by state institutions, gives frontiers their own particular characteristics. This advances the conceptualization of the frontier towards a pluralistic point of view that embraces the diversity of frontier experiences and isolates it from any overarching grand theory or single master principle.

The present study builds on this latter concept of the frontier, involving both a geographic and temporal dimension but lacking the deterministic nature of the earlier definitions. Since the study (dissertation) is concerned with understanding changes in land cover and land use it is important to consider that the frontiers in question are agrarian frontiers that involve land conversion processes⁹. It recognizes the complex, dynamic and heterogeneous nature of frontier processes as more recent studies have shown (e.g. Cleary 1993; Browder and Godfrey 1997). The frontier is defined then as the geographic place where different socioeconomic or cultural groups contend, compete and coexist with each other and with their physical environment creating their own unique dynamic and thus shaping its own social and environmental fabric. The frontier is then understood as both a place and a process, linked inextricably. How long does a frontier last for? Turner had predicted the end of the frontier with the end of available “free” land for settlers to keep moving westward. In this sense the state of Rondônia can be considered a post-frontier, although processes of social and environmental change are still in flux and the defining nature of the post-frontier is still far from defined. This dissertation attempts to analyze and interpret social and environmental change as the region has moved from a frontier to a post-frontier scenario.

In the rest of this chapter I review conventional theories regarding the relationships between frontier expansion and the environmental and social processes that follow. Specifically, this chapter critically reviews the main bodies of literature that have

⁹ Historians use a more broad definition of frontier, considering them as “geographic zones of interaction between two or more distinctive cultures.” (Weber and Rausch 1993: xiv).

addressed frontier dynamics in Amazonia and the theories that have shaped our current understanding of frontier evolution and processes. The first section reviews the predecessors of current frontier theories in the Amazon, including Turner's original frontier thesis. The second section focuses on the literature that deals with the frontier in the Amazon region and how they have been applied to questions of land use change. I focus on the household life cycle theory which has been one of the most influential for modeling land use change processes in Amazonia. I conclude with a revised model of the household life cycle that incorporates important additions from post-structuralist frameworks.

Background

The birth of the frontier myth: Frederick Jackson Turner and the “Frontier Thesis”.

The existence of an area of free land, its continuous recession, and the advance of American settlement westward, explain American development.

Frederick Jackson Turner ([1893] 1961).

The frontier as a concept attained prominence, more than a century ago, with Frederick Jackson Turner's historic essay “The Significance of the Frontier in American History”, the source of the above quotation. Although the audience at the American Historical Association conference in 1893 was indifferent to Turner's presentation, by the early 1900s it became the most important essay for explaining American history and its institutions. It gained popularity by explicitly connecting several ideas that were being discussed at the time among intellectuals and political figures on the relevance and importance of the frontier setting to the development of the American nation¹⁰. He was

¹⁰ Billington (1971) reviews the extensive discussions and letters between Woodrow Wilson and Frederick Jackson Turner before the presentation of the essay in 1893 while they were both at John Hopkins (1888-1889) and during Woodrow Wilson's visit to Madison, Wisconsin, in 1892. A year before Turner's essay Woodrow Wilson had already written a critical review of the book by Goldwyn Smith, *The United States: An outline of Political History 1492-1871*, in which he critiques the book's emphasis on the role of New England in shaping American development, discrediting the role of the South and the West in this process. Woodrow Wilson's observations about the role of the Western frontier in the development of America closely resemble Turner's argument in his essay which was presented the year following Wilson's visit. On another account, Theodore Roosevelt wrote to Frederick Jackson Turner in 1894 thanking him for a copy of

the first to articulate a comprehensive theory of the frontier as a spatial construct that was not only important for building the nation, but one that was continually molding and defining American culture, institutions and identity. Before Turner, scholars had used frameworks based on the relevance of European institutions to explain historical processes shaping the new continent¹¹. For a nation constantly looking to define itself as unique, sovereign and independent of the European legacy, Turner's essay was received enthusiastically. America could finally break itself not only politically but also conceptually from its European predecessors. The frontier theory represented a paradigmatic shift in the analysis and construction of American cultural identity.

Turner's main argument is that the frontier environment and its continuous expansion were crucial factors in shaping the American character and American political institutions. According to Turner, inherited European skills were not relevant in the new conditions of "untamed nature" that New England and European settlers found on the Western frontier.

Thus American development has exhibited not merely advance along a single line, but a return to primitive conditions on a continually advancing frontier line, and a new development for that area. American social development has been continually beginning over again on the frontier. This perennial rebirth, this fluidity of American life, this expansion westward with its new opportunities, its continuous touch with the simplicity of primitive society, furnish the forces dominating American character (Turner ([1893] 1961: 32).

The essay was revolutionary in that it emphasized how the environment shaped the character of the frontiersman. Old World values had to be replaced. The frontier environment had created the conditions in which evolved those characteristics that Turner recalls being cherished by Americans—individualism, a democratic spirit, inventiveness, optimism, a distrust of government intervention, and a belief in self-help. This eventually led to what Turner designated the American version of a democratic society.

American democracy is fundamentally the outcome of the experiences of the American people in dealing with the West. Western democracy through the whole of its earlier period tended to the production of a society of which the most

his 1893 address, "I think you have struck some first class ideas ... and have put into definite shape a good deal of thought that has been floating around rather loosely." (Nash 2001: 149).

¹¹ Most historians at the end of the 19th century adhered to the "germ theory" which explained the genesis of a nation's institutions as evolving from a European institution, in the case of the United States from England, and beyond that from its "germ" in medieval Germany (Billington, 1971:3).

distinctive fact was the freedom of the individual to rise under conditions of social mobility and whose ambition was the liberty and well-being of the masses. This conception has vitalized all American democracy, and has brought it into sharp contrasts with the democracies of history and with those modern efforts of Europe to create an artificial democratic order by legislation (Turner ([1893] 1961: 95).

The ideas proposed by Turner were not unique to the American context. In Brazil in 1889, four years before Turner presented his theory to the American Historical Association (AHA), a Brazilian historian, Capistrano de Abreu, published a book entitled *Os Caminhos Antigos e o Povoamento do Brasil*. In it, he advances the theory that the movement of the agricultural frontier into the *sertão*, or backcountry, was responsible for the country's character (Billington 1971: 85). Abreu argued that the movement of pioneers into the *sertão* transformed the first settlers into savages, then, as the *sertão* became "civilized", so did the settlers. The result was a new cultured citizen, with a new personality that distinguished him from his Portuguese ancestors. Billington (1971) suggests these apparently unrelated but similar theories were not merely coincidental. He argues that it was the social context and the intellectual climate of the time that allowed both historians to reach similar conclusions independent of each other¹². On one hand, as two newly independent nations, its citizens were looking inward for their own interpretations of a national identity that will liberate them from their colonial ancestry. In the case of the United States, there was also great concern among politicians and writers about the closing frontier over its citizens, especially in a context of great migration waves from Eastern Europe, Italy and Ireland. On the other, advances in methodological tools in history and geography, such as annual censuses and demographic maps, allowed both historians to study frontier regions from previously unavailable perspectives. Furthermore, theoretical advances in the sciences, particularly Darwin's evolutionary theory, had a profound influence over other schools of thought, especially on the prominent role of the environment and the emergence of a concept of society as a continuously evolving organism, both linked to the concept of frontiers as evolving and influencing human character. Thus, the intellectual and social context of the time,

¹² Billington adds similar conclusions were being reached at the time in other research areas such as in anthropology by Dr. C. Hart Merriam and in geography by Halford J. Mackinder (1971: 85-86).

allowed both historians, Turner and Abreu, to arrive at similar conclusions independently from each other, but almost parallel in time.

Despite the initial commonalities between Abreu and Turner, few Latin American scholars, including Brazilians, have claimed that their frontiers had a positive Turnerian effect over their colonizers. In fact, Latin American frontiers have been associated with negative attributes, both in scholarly and popular literature. For example, Weber and Raush (1994) point out how in early novels depicting frontier life in Latin America, the encounter between man and wilderness ends in failure rather than in triumph¹³. Nonetheless, some Latin American have argued that frontiers forged important features of their national identities, as is the case of the *bandeirantes* in Brazil (Ricardo 1970). A comparative view of the North American frontier and its Latin American counterparts has been explored by Alistair Hennessy (1978) and is reviewed in a section of its own below.

Considering that frontiers had different impacts throughout Latin America than those imagined by Turner for the United States¹⁴, two important features of the frontier thesis that remain relevant in the Latin American context are; (1) the frontier as an important field of inquiry for understanding the cultural, economical and historical features of a region¹⁵, and (2) the persistence of several Turnerian themes in policies that promote frontier expansion. While the positive attributes of the American frontier might not be shared with its Latin American counterparts several Turnerian themes have had lasting influence over public policy in several countries, especially in Brazil. The military's conceptualization of Amazonia as a "safety valve" to resolve social pressure for land reform in the southeast and the relocation of the Brazilian capital into the

¹³ These novels include Brazil's Euclides da Cunha *Os sertões* (1902) and Jorge Amado's *Terras do sem fim* (1943), Venezuela's Romulo Gallegos, *Doña Barbara* (1929), and Colombia's Jose Eustacio Rivera, *La voragine* (1924).

¹⁴ Those that argued for similarities between the North American frontier and Latin American frontiers include American historians, Herbert Eugene Bolton (1933), and Arthur Aiton (1940), and the Argentinean historian Hebe Clementi (1986).

¹⁵ Turner ([1893] 1961) emphasizes this point in the initial section of his essay "Much has been written about the frontier from the point of view of border warfare and the chase, but as a field for the serious study of the economist and the historian it has been neglected. . . . This paper will make no attempt to treat the subject exhaustively; its aim is simply to call attention to the frontier as a fertile field for investigation. . . ." p. 3. The study of frontier regions in the in Latin America has allowed advancing our understanding of how frontiers shaped Iberoamerican societies. Weber and Raush (1994) provide a comprehensive book of previously published essays about Latin American frontiers.

hinterland of the country can be traced back to Turner's version of the frontier¹⁶. After the 1930s the colonization of the interior in Brazil is linked to a nationalist ideology and state policy for relieving social pressure for land reform (Toni 1999; Barbosa 2000).

An equally important theoretical legacy of the Turner thesis is the linear stages approach it presented. Turner observed that a recurrent pattern was that the frontier progressed through distinguishable stages, each characterized by different types of settlers, following each other in waves that swept across the nation. The frontier process ended when the land was consolidated into stable agricultural production units, permanent forms of infrastructure were established (e.g. roads and railways) and frontier settlements evolved into towns. Turner emphasizes how the process repeats itself, becoming an inherent characteristic of frontiers across the United States. The theme of frontiers moving through stages and finishing in a consolidated phase has had a strong influence on Latin American researchers' conceptualizations of the frontier in tropical forested regions (e.g., Moran 1984, 1989; Findley 1988; Thiele 1993). These "frontier transition" or "frontier stages" models will be reviewed in a subsequent section.

Critics of the Turner thesis have been as numerous as his advocates. It has been argued that only a small percentage of Americans were subjected to the frontier experience, that it reflects the prejudices of the 1890s, that Turner's use of metaphors was misleading, that he excludes from history the real characters of the frontier (e.g., the land speculators and the railway companies), and that the values taken to the frontier were more important than the frontier environment was in shaping new values. However, it cannot be denied that the frontier thesis has had an overarching influence over our conceptualization of the West and its influence on the development of American institutions. Moreover, the frontier myth expanded beyond the borders of North America to influence the rhetoric and practice of development planners in the Third World (Katzman 1977: 3-5). This has been especially influential in Brazil and specifically in the Amazon region where the abundance of land and scale of migration have been comparable to those experienced in the North America West one hundred years before.

¹⁶ Billington in referring to letters written by Turner before the presentation of the frontier thesis recalls several passages that resonate the foundations of the modern day "safety valve" thesis— "The quick settlement of lands in small farms has, I judge, prevented the absorption of such territory into great states" (1971:36).

What have been the implications of carrying the frontier concept into the Brazilian context? How have Brazilian scholars differed from their North American counterparts in conceptualizing the frontier? These questions continue to be relevant in the ongoing discourse over the Amazonian frontier. While images of frontier expansion in Latin American continue to evoke forest destruction and social injustice, the Turnerian “frontier myth” continues to haunt development agencies and planners that hope to find in the frontier the natural resource endowments with which to fuel the continuation of the economic growth and progress of a developing nation like Brazil.

Carl Ortwin Sauer: Frontiers as cultural successions

The human geographer has the obligation to make cultural processes the base of his thinking and observation.

Carl Sauer (1967: 378).

Carl Ortwin Sauer, like Turner, grew up in the frontier setting of the Midwest but during a very different historical period. While Turner grew up in the midst of frontier expansion, Sauer witnessed the end of the homestead and with it the transient nature of many of the “positive” attributes of the frontier region. These experiences and his acute feeling for the importance of the historical and environmental context of different frontier settings throughout his studies led him to a different interpretation of the frontier process.

Integrating his background in geography and ecology, Sauer studied the relationships between people and their environment, which featured detailed attention to the contextual geophysical characteristics and temporal factors of the frontier process. Sauer mixes his keen interest and firm knowledge of climatology, geomorphology and ecology, with his equally important studies of historical narratives for the interpretations of frontiers. This environmental and historical approach to the study of frontiers led to his conceptualization of frontiers as “cultural successions” analogous to the concept of vegetative successions used in plant ecology¹⁷. Unlike Turner’s more linear and

¹⁷ Carl Sauer was influenced in his concept of cultural successions by his early studies at the University of Chicago with plant ecologist Henry Chandler Cowles (Leighly 1967: 2). Cowles was a trained geologist who studied the dynamic interaction between plant distribution and underlying geological formations. This physiographic perspective in ecological studies viewed the flora of a landscape as an ever-changing panorama. His study on dunes was the first to work out the complete successional series of a vegetation

deterministic approach to frontier stages, for Sauer the successions characterizing the frontier process are strongly mediated and shaped by the historical and geophysical characteristics in which a particular process is embedded¹⁸. Based on Cowles' studies of vegetation successions (Cowles 1899), frontier stages are never linear, nor do they reach a "climax" or "equilibrium" stage. Although frontier stages tend to follow a series of successions, these are mediated by their physical, historical and cultural context. For Sauer, landscapes are the result of a cumulative process whereby each stage conditions the next, the most important of which are the initial conditions of the settlement. Therefore, the pathways of distinct frontiers will differ considerably depending not only on the initial conditions, but also on emergent forces that arise over time and how the particular environmental and geophysical characteristics shape these. The result is myriad frontier processes and outcomes that contrast with the general stage-step approach of Turner. On this Sauer wrote:

It has been customary to speak of a frontier, supposed to develop in the successive stages of the human-trader-trapper, the herdsman, the farmer, and the final dominance of the city dweller... No groups coming from different civilizations and animated by different social ideals have reacted to frontier life in identical fashion... the eternal pluralism of history asserts itself on the American frontier: there was no single type of frontier, nor was there a uniform series of stages. The nature of the cultural succession that was initiated in any frontier was determined by the physical character of the country, by the civilization that was brought in, and by the moment of history that was involved (Sauer [1940] 1967: 49).

system (Cowles 1899). While Cowles believed that succession tended toward equilibrium, he did not believe this equilibrium was ever reached. Cowles' ecological studies differed significantly from those presented by the main plant theoretician of the early 20th century, Frederic Clements (Real and Brown 1991). Clements relied on statistical and graphical analytical methods to present the concept of ecological succession. In this theory, a plant community is treated as a "complex organism" with a life cycle of its own and evolving just as individual organisms evolve. This contrasted with Cowles' view of succession, in which stages were never linear and could actually regress from their expected course. While Sauer maintained Cowles' more dynamic view of ecological succession in his cultural succession analogy, Clements' evolutionary view predominated in the ecology field until the 1950s. A complete discussion of these paradigms and their historical influence over the theoretical schools in ecology is explored in the introduction of Leslie A. Real and James H. Brown's book *Foundations of Ecology: Classic Papers with Commentaries* (1991).

¹⁸ Turner himself will come back to these ideas in his unpublished book *The Significance of Sections*, in which he draws particular attention to the importance of the physiography of the region in molding the sequence of complex societies that sprung "from the ashes of the ever-retreating frontier" (Steiner 1995: 483). Although Turner spent many of his last years developing the idea of Sections, analogous to regions, and, ironically, addressing many of the issues that were later raised by his critics, these have rarely been acknowledged (Steiner 1995).

Carl Sauer and his legacy of inquiry over the geography and other interdisciplinary studies has allowed for alternative conceptualizations of the frontier rooted in the indivisibility in the landscape between man and his environment, both influenced by each other. By focusing on the unique components of the process instead of the generalizations, the frontier is no longer a replicable process across the landscape as in Turner's thesis. Instead the landscape is constantly molded, the result of the interactions between humans and the environment at different points of the frontier process.

The insights gained from regional studies and the importance of understanding the plurality of frontiers on a larger temporal and spatial scale than the case study approach of cultural geographers lead to review more recent efforts by historians to conceptualize the frontier. One of the most comprehensive historical studies of frontiers across Latin American has been the one presented by Alistair Hennessy.

Alistair Hennessy and the comparative historical approach: The plurality of frontiers in Latin America

Does a Latin American culture exist? ... to question our culture is to question our very existence, our human reality itself, and thus to be willing to take a stand in favor of our irremediable colonial condition.

Roberto Fernandez Retamar (2004: 83)

Is Latin America more than a metaphysical concept or a geographic expression?
Alistair Hennessy (1978).

Following the tradition of Turner's frontier thesis, Alistair Hennessy proposes that to understand Latin America, one should analyze how its different frontiers were occupied and conquered. To "study the problem of territorial space and its conquest... this has been common to all Latin American countries, large and small, and it is something which they share with the United States and Canada." (1978: 1). For Hennessy, a comparative study of the historical processes of colonization in Latin America becomes the venue for understanding the commonalities and differences

between the multiple regions that comprise it. The comparative approach sheds light on how different frontier processes result in distinct social and environmental outcomes.

Success or failure to solve the problems of settlement lies at the root of many of the continent’s difficulties ... an analysis of those successes or failures and of what is cause and what effect takes us to the heart of the Latin American predicament... then the study of frontiers of settlement in the North American sense (Turnerian approach) can be a useful heuristic device for organizing and giving coherence to a mass of otherwise intractable material. (Hennessy 1978: 2)

Hennessy shows us how the concept of the frontier becomes an ideal framework for analyzing and comparing the mosaic of regional differences that characterizes the Latin American landscape. The Amazon frontier is just the last in this series of frontier openings that have historically shaped and reconfigured the Latin American landscape and its inhabitants.

For Hennessy, in Latin America there is no West, “there is no Frontier, there are only frontiers (1978: 6).” While in the United States, the existence of one great Frontier, and the myth that it begat, explain the solidification of American culture and institutions, the plurality of frontier types in Latin America explains the greater diversity of cultures and landscapes that characterizes Latin America today. The distinctions between the Latin American frontiers and Turners conceptualization of the frontier are summarized in Table 1.

Table 1. Comparison of the American frontier and Latin American frontiers. Based on Hennessy (1978)

United States of America	Latin America
The frontier (West)	Many frontiers (plurality of frontier types)
Individualistic democratic rural institutions – rural homestead	Paternalistic authoritarian rural structure – <i>latifundios</i>
Elimination of natives – exclusion of natives from frontier process	Miscegenation – natives are absorbed into the frontier process through racial inter-mixing

Consolidation of frontier farm homesteads in the frontier	Hollow frontiers – boom and bust phases to frontiers
Surplus of labor	Scarcity of labor
Innovation was inherent to the frontier process as land became scarce	Resistance to innovation due to land abundance
New democratic institutions implanted	Archaic social and economic organizations and institutions

Unlike Turner’s linear and definitive vision of the frontier in the United States, for Hennessy the majority of Latin American nations today are still in the frontier stage of development. Hennessy believes this may be due to a “pervasive influence of the past”. While Turner’s “wild” frontier symbolizes the individuation of America’s cultural identity from its European legacy, Latin American frontiers draw from processes of mixtures of Iberian cultures with those of the new continent.

Latin America is dominated by a complex interweaving of both space and time. It is not easy to jettison cultural baggage in the Latin American environment. Monuments, whether Precolumbian or colonial are ubiquitous and the greater degree of racial intermixing has bequeathed a complex pattern of varied cultural traditions and contrasting ways of looking at the past. There is overall—an Iberian *modo de ser* (Hennessy 1978: 3).

Thus, Hennessy prepares the reader for the problems of translating the frontier thesis to Latin America where, unlike the American frontier, the Latin American experience is shaped as much by the cultural factors as it is by the environment. While in the United States, the Turner thesis relies heavily on the power of the environment to determine the new traits of American individualism and institutions, the cultural influence of Iberian immigrants and of the indigenous peoples inhabiting Latin America weighs heavily in shaping the Latin American frontier. Thus, it will be interesting to explore how these observations play out in the Amazon region and how different scholars have adapted the frontier thesis to the Amazonian hinterland.

The lack of a frontier myth in Latin America bewilders Hennessey. Among the reasons he finds for this is the different role of the historian in Latin America and the different questions arising in the Latin American context. While Turner found an enthusiastic public willing to hear about the endogenous reasons for material progress and democratic advance in the United States, prevailing feelings of backwardness and underdevelopment required a different kind of explanation from Latin American scholars. The postulates of capitalism, which frame Turner's frontier thesis, become the main points of criticism for Latin American scholars (e.g., Foweraker 1981, Pomper Mayer 1984, Souza Martins 1975, Cardoso and Faletto 1978). The failures of capitalism in Latin America and the feelings of dependence this has caused among its population defy a frontier myth in the Turnerian sense. Therefore, it is not surprising that a political ecology framework that questions the essence of capitalist forms of frontier expansion dominates Amazonian frontier literature (Cleary 1993). A review of this literature will follow in the next section of this chapter. Hennessey's work does not use the dialectical approach to understand frontier development in Latin America, but his comparison of the differences of North American and Latin American frontier experiences sets the stage for understanding underlying differences between these continents and the motivations behind current scholarly work in analyzing the Amazonian frontier.

Other scholars have studied Latin American frontiers and have reached similar conclusions, although many do not make any references to the Turner frontier thesis. Weber and Raush (1994) compile a set of 19 essays from different Latin American and American writers on the Latin American frontiers and conclude that "throughout Latin America, frontiers had different impacts than those imagined by Turner for the United States (1994: xxxi)." Despite this they recognize the significant role frontiers have played in shaping the new Iberoamerican societies, nonetheless much more varied and heterogeneous in its outcomes. Also, as Hennessey, they conclude that Latin American frontiers became places with much more racial and cultural blending, especially in its beginnings, allowing a certain degree of social mobility for natives that was not found in its North American counterpart. Over time the nature of Latin American economic and political institutions became highly present in the frontier, limiting social mobility and maintaining inequality. Therefore Latin American frontiers did not capture the

imagination of the public, nor were they regarded important for Latin American scholars for explaining their national cultures or institutions. These darker views of the frontier process have extended themselves into the analysis of contemporary frontiers, especially in the Amazon region and are the subject of the next section.

Conclusion and Synthesis

Historians, geographers and regional planners have shaped our theoretical understanding of frontier processes. Particularly important has been Turner's frontier thesis, in which he proposes that the overarching experience of how the frontier was settled gave way to the unifying character and institutions of the American nation. Carl Sauer questioned the environmental determinism of the frontier experience and presents instead the concept of "cultural successions", stages through which different frontiers have to go through but that vary with the terrain, and historical influence of the fauna and flora in the place. In a similar vein, but using a comparative historical approach, Hennessy proposes that the cultural and environmental diversity found in Latin America is due to the myriad of frontier experiences that have evolved over time. These authors wrote about frontiers before the opening of the Amazonian frontier. However, they inform our understanding of the consequences of the opening of the Amazon as an agricultural frontier. Additionally, the positive attributes embedded in the conceptualization of the Turnerian frontier model had an impact over development planners and government officials that promoted colonization programs in the Brazilian Amazon. More recently, these frontier theories have informed scholars interested in Amazonian development in their projection of social and environmental changes that will occur because of the opening of the Amazonian frontier. The next section reviews these main bodies of literature.

The Contemporary Frontier: Conceptual frameworks

The previous sections reviewed the traditional frontier theories that provide the conceptual foundations for contemporary theorizing about the Amazon as an agricultural

frontier. This section of the chapter reviews the theoretical approaches designed to understand the social and environmental changes over time of the smallholder farmer frontier. Based on previous typologies¹⁹, I classify theoretical frameworks that attempt to explain frontier change in the Brazilian context into one of four different groups: political economy theories, household demographic and life cycle stages, economic geography and disarticulated frontiers. I argue that while these theories are based on different notions of ecology, economy, and human agency, they are not mutually exclusive. Each emphasizes different aspects of the processes of frontier expansion that helps us understand environmental and social change in the Brazilian Amazon.

Political economy theories, mostly grounded in neo-marxist philosophy, foresee the displacement of peasant forms of production in frontier regions by the expansion of capitalist modes of production. This theoretical lens includes a wide range of scholars who have different approaches to understanding the dynamics and outcomes of frontier expansion, but fall into two dominant schools: those that emphasize local modes of production and internal inequalities (modernization theories) and those that emphasize increasing external core-periphery inequalities (dependency theories). All political economy perspectives stress the sociopolitical nature of relations of production. Amazonian scholars have used these theories to build their own “indigenous” explanations of capitalist expansion in the region (e.g., Becker, Sawyer, Pompermayer). Still, political economy theories share a structuralist approach to explaining the outcomes of frontier dynamics, in which the dialectical confrontation between capitalists and peasants is an inherent characteristic of frontier evolution.

Household demographics and life cycle theories conceptualize frontiers as moving through a set of predictive stages, determined by the demographic profile of the frontier population as it moves through its household life cycle, which influences its subsequent land use strategies (Moran 1989; Walker and Homma 1996; McCracken et al. 1999). Based on Chayanov’s thesis of noncapitalist forms of peasant behavior in Russia at the turn of the 19th century, life-cycle models have seen a resurgence in the Brazilian Amazon literature where a context of land abundance and labor shortages are also characteristic (e.g., Perz and Walker 2002; Walker et al. 2002). These theories stress the

¹⁹ These include: Heynig 1982; Jolly 1991; Browder and Godfrey 1997; Murphy 1998

internal characteristics of the population, household livelihood strategies and adaptation processes colonists go through as the main explanatory variables of land use strategies and social outcomes. It is thus abstracted from the conflicting dichotomy that is inherent in the Marxist approach of capitalist versus peasant forms of production. Additionally, it emphasizes the competition and adaptation processes of small landholders as a social group through time rather than representing a survival of the peasant form of production. Land use and social change become explicitly deterministic, based on the life cycle of the household. A more recent variant of the household life cycle is the concept of linear frontier stages. Since, it is presumed, most households arrive at a frontier region about the same time, the phases that frontier settlements go through resemble a progressive series of stages whose land use options are constrained by family labor, capital and natural resources in the area. In an analogous way, land use and social change will be determined by the stage at which the frontier is staged at (Browder and Godfrey 1990).

Economic geography or spatial economic models emphasize the interface between commodity markets and spatial attributes (e.g., distance to markets) for different agricultural products. Theories linked to this approach include central place theory, location theory and diffusion theories, all of which assume a hierarchical deterministic logic to the spatial expansion and structuration of the agricultural frontier. Building on a neoclassical economic paradigm, and abstracting from contextual forces (e.g., local politics), the spatial organization of frontier settlements and their expansion are the outcome of the distance of the frontier region to the markets with the marginal rates of return for different agricultural products. Frontier expansion assumes a predictable economic evolutionary pattern consistent with modernization theories and spatial economics (e.g., the Von Thunen model).

Disarticulated and contested frontiers emphasize the existence of a plurality of frontier types that are not necessarily structured by a single overarching economic system. On the contrary, this frontier theory emphasizes the disarticulated character of present frontier change and contends the importance of frontiers as contested spaces that are not necessarily linked to the regional economy in a predictable way. In an increasingly globalized world, frontiers are sometimes shaped by forces beyond the regional or national level, challenging conventional models of hierarchy and distance to

markets as postulated in spatial economics and world system models. This contrasts with the conceptualization of the frontier as a homogenous experience, relying instead on the mesolevel context as the driving force influencing frontier outcomes. While political ecology, spatial economics and household demographic theories delineate an overarching framework to explain changes through time (capitalist expansion in the first theory, markets and production costs in the second and household demographic stages in the third), contested and disarticulated frontier theories point to the importance of the subregional contexts mediating the social and land use outcomes of frontier change (Browder and Godfrey 1997).

Peasants and Capitalists: Political economy perspectives

Using the classification of Browder and Godfrey (1997), structuralist political ecology theories are classified into one of three groups; (1) capitalist penetration perspectives, (2) intersectoral articulation models, and (3) world system theories. Each is reviewed below.

Capitalist Penetration Theory

The capital penetration theory stresses the role of the expansion of capitalist modes of production into rural areas and the subsequent impact on land ownership and the local population. This theory usually takes a historical linear stages approach and emphasizes a progressive substitution of peasant modes of production for capitalist modes such as cattle ranching and agroindustry. In a characteristic capitalist penetration approach, Joe Foweraker (1981) presents the advance of pioneer frontiers in Brazil as a set of predictable stages from noncapitalist to capitalist forms of production. In this model, the accumulation of capital pertains to the intermediaries, the state bureaucrats, the local elites and eventually to the corporate agricultural enterprises that take over the frontier and appropriate the labor value of the small landholder farmers work which is held in the frontier land that they have opened²⁰. This process does not go uncontested,

²⁰ According to neo-marxist economic theories, capital is held in the land that has been opened up by the labor of the peasant farmer, thus by taking over the land, capitalist interests are appropriating the capital that the peasant farmer has accumulated over time.

and an intrinsically violent process usually results between peasants and the dominating classes in which the long-term outcome is usually the appropriation of land by powerful entrepreneurs and companies. This creates the surplus labor that is required for these new forms of production and for the opening of new areas of frontier expansion.

A similar view is offered by Brazilian sociologist Jose de Souza Martins (1975) who defined two conflicting and overlapping types of frontier that take place in the initial processes of frontier expansion. First, the “demographic frontier” characterizes the settlement of remote areas by small landless farmers that are encouraged to leave their regions of origin by the promise of available land on the frontier, labor displacement by agricultural technification, and the construction of roads towards frontier regions. The second, the “economic frontier” follows, driven mainly by capitalist enterprises such as ranchers and multinational companies. When the economic frontier catches up with the demographic frontier, capitalist enterprises attempt to control and appropriate the means of production leading to conflicts and consequently land once again becomes scarce.

An alternative view using a different slant on the structuralist framework of analysis was offered by Donald Sawyer (1984), who described the Brazilian Amazonian frontier as being constantly shaped not only by the expansion of the capitalist modes of production into the region but also by its subsequent retraction as well. David Cleary (1993) considers Donald Sawyer and the Amazonian school of political economy that follows as a revisionist trend that tried to reconcile many of the shortcomings of previous neo-marxist scholarship. In Sawyer’s model, the frontier is not only a set of progressive stages from precapitalist to capitalist modes of production, but takes the form of a cycle, whereby the frontier is abandoned and depopulated as speculative fronts take over the land. Sawyer identifies the processes guiding the expansion and retraction of the demographic and economic frontiers as being “spatial manifestations” of the same process, an increasing reliance on capitalism as the principal development paradigm in Brazil. For example, frontiers move to take over primary products (e.g., rubber, sugar), stagnation or retraction occurs when the same processes cause production to move elsewhere (e.g., West Indies for sugar, Southeast Asia for rubber). Out-migration from rural areas into regional cities and new frontiers are thus the result of larger structural forces that are operating at the national and international levels.

An important contribution of capitalist penetration theory to understanding frontier expansion in the Amazonian frontier has been linking the processes of agricultural modernization in the southeast to the migration patterns into Amazonia. The immense population exodus into the Amazonian frontier experienced during the 1970s and 1980s was mainly spontaneous and not the result of state-sponsored settlement projects. Policies and programs to promote frontier development were discontinuous and modest (Foweraker 1981; Sawyer 1984). Only 5% of the population was settled in planned settlement patterns sponsored by the state. Capital penetration theorists have shown the linkages between capitalist development and industrialization of agriculture in the southeast with the subsequent displacement of sharecroppers and their migration into Amazonia. Therefore, capitalist penetration theorists argue that it is the larger national and global structural forces of capitalism that guide processes of migration and environmental degradation in Amazonia. This observation led capital penetration theorists to hypothesize that the processes of agricultural modernization and the subsequent displacement of peasants experienced in southeastern Brazil would eventually catch up in Amazonia, displacing the small landholder farmers once more further onto the frontier. The displacement of peasant forms of production by capitalist modes of production fueled by the modernization of agriculture in complicity with state policies is at the core of capitalist penetration theories.

Another recurrent theme among the capitalist penetration theories is the emergence of “speculative fronts” (Sawyer 1984). The role of the speculative frontier, supported by governmental policies that favored the allocation of vast expanses of land to the private corporatist sector, caused a “political or juridical” closing of the frontier (Sawyer 1984). Specifically important in the Brazilian Amazon were the enormous institutional rents subsidized by SUDAM through fiscal incentives during the 1970s and early 1980s to “arm-chair” cattle ranchers²¹ (Bunker 1985; Browder 1988; Mahar 1990). In this scenario, outside capital and speculative forces take over the land but are unable to make it productive, leaving in its place a depopulated “hollow” frontier (Sawyer 1984; Bunker 1985). Sawyer describes this process as one in which speculative fronts jump

²¹ A comprehensive review of the pervasive fiscal incentives during the 1980s that encouraged wasteful deforestation and subsequent abandonment of vast areas of land during this period is presented in Chapter IV as part of the historical review of development phases in Brazil.

ahead of the economic and demographic fronts, causing an artificial closure of the frontier and limiting the availability of land for landless farmers (Sawyer 1984). Schmink and Wood (1992) describe this process in their case study in Sao Felix do Xingu.

Despite apparent abundance, the land available for small farmers near the town of Sao Felix was quite limited. While vast areas remained unoccupied, much of the municipality's land was already claimed when the migrants arrived. Sao Felix was a place where the usual frontier cycle had been 'closed' off by the actions of government agencies, land developers, and large ranchers to take possession of huge tracts of land. One migrant summed it up: 'People say there's lots of public land here. You get here—and it all has an owner' (Schmink and Wood 1992: 306).

However, speculative fronts do not necessarily become land under production. The interest of capitalists turns to land as a way to temporarily store value, especially during the hyper-inflationary 1980s, or as a source of future rent to subsequent, "follow-on" corporate migrants to the "post-frontier" (e.g. multinational cattle and soy bean interests).

The capitalist penetration theory foresees a post-frontier setting characterized by the displacement of the first generation pioneers, the "peasant form of production" and the appearance of a demographically "hollow" frontier as modern and capitalist modes of production take over the most productive lands. In this scenario, peasants are physically replaced as the main source of production by capitalist (mechanized and low input) forms of production such as soy bean production and cattle ranching. These require limited labor force or temporary labor and thus peasants seeking more stable livelihood situations (e.g. those just starting a family, and thus entering the initial stages of a household life-cycle) move further along the frontier or accumulate on marginal lands and in urban centers that serve as "holding pens" for surplus labor to be used when needed. Unlike intersectoral articulation models, capitalist penetration models predict the displacement of peasants from the land, the concentration of these peasants in urban centers on the frontier and the predominance of new forms of capitalist enterprises, especially ranching, edible vegetable oils (soy), both, likely to be preceded by a short-lived interval of timber extraction, all oriented toward global markets.

Intersectoral articulation theory

Unlike the capitalist penetration theory, that predicts the total displacement of noncapitalist forms of production by capitalist ones, the intersectoral articulation model explains the persistence of peasant forms of production in an otherwise capitalist system (Roberts 1978; De Janvry 1981). Therefore, a traditional or small peasant rural economy is purposely maintained due to the functional role they play in securing the accumulation of capital in the urban and industrial sectors. Agricultural frontiers are articulated to urban industrial centers through peasant forms of production who subsidize capital accumulation in the industrial centers by keeping rural wages down and a continuous supply of food products at below production costs (Sorj 1980; Foweraker 1981). This can only be accomplished by the continuous opening of the frontier where peasant forms of production can expand while urban areas go through accelerated industrialization processes. Therefore, the capital accumulation in the industrial sector of the Brazilian Southeast is subsidized by the expansion of peasant forms of agricultural production in the Amazonian frontier.

Malori Jose Pompermayer²² (1979) applies the intersectoral articulation model to the Brazilian Amazon. Pompermayer argues that the processes of capitalist accumulation in the industrial and urban sectors (especially in the Center-South), subordinates other economic sectors such as agriculture. The state, supported by a political coalition of interest groups from the industrial and agroindustrial classes, creates the conditions for an urban-industrial development while maintaining the peasant agrarian structure and conditions intact. This means *latifundiarios* maintain their political and economic power untouched²³. Instead, agriculture expands through the incorporation of new lands at very low rates of capitalization. The traditional agriculture sector feeds a constant supply of cheap labor power to industry through internal labor migration to the frontier while producing agricultural crops for urban centers and raw materials for the industrial sectors at low costs. The large flow of migrants and the availability of staple crops at minimum

²² Malori Pompermayer is heavily influenced by the writings of another Brazilian Marxist scholar, Bernardo Sorj, who used the same theoretical framework to analyze the perpetuation of peasant modes of production in southern Brazil and the appearance of São Paulo as the main urban industrial center of Brazil (Sorj 1980).

²³ This runs counter to the conventional marxist argument that the *latifundio* is an obstacle to the development of capitalist relationships of production, suggesting instead the adequacy of these traditional structures for capital accumulation.

prices reinforce the maintenance of low incomes for the working class. Thus, traditional agriculture based on abundant land and labor facilitates the accumulation of capital in the industrial sector. Even areas like the Central South, where more modern commercial and even capitalist forms of agriculture exist, still create and recreate primitive subsistence production at the margins and periphery of the system. Similar articulations exist between regions, whereby the successful urban and industrial development of the Central South is also responsible for the impoverishment of the Northeast.

This model envisions an Amazonian post-frontier where peasant forms of production persist, producing staple crops for the urban population. Frontiers become articulated to other economic sectors, primarily located in the Central South while maintaining a production system that is traditional and noncapitalist in nature. While regions become increasingly articulated to other economic regions, the forms of production and the traditional agrarian structures of tenure and exchange remain unchanged. Mandell (1960), cited by Pomper Mayer (1979), recalls an agricultural frontier in the Brazilian state of Goiás²⁴ that now resembles the post-frontier in the present Amazon region.

In the late nineteenth century, the formation of the São Paulo coffee economy and attendant urbanization encouraged railroad construction and greater trade between central Brazil and the coastal cities. The Southern Goiás-Brasília Region participated in this growth by expanding its cattle trade and increasing its sales of household and cottage-processed foodstuffs. The reintegration of the economy of central Brazil into the national economy began between 1890–1930. Distant zones specialized in raising calves and yearlings, ranches located closer to market, in feeding two or three year old animals, and those nearest to rail and slaughter centers to finishing animals for slaughter (Pomper Mayer 1979: 12).

Mandell noted that while cattle shifted from having a purely subsistence value to having a commercial value, the overall cattle production system in the frontier remains unchanged. Pomper Mayer notes that the processes underway in the Amazon are not different from those described by Mandell. In this model, frontiers become articulated to centers of production of goods that are essential for the accumulation of capital in the urban and industrial centers of the southwest. Subsistence forms of production are replaced by the production of market commodities. However, the overall structure of modes of

²⁴ The state of Goiás is located in central western Brazil and has an immense extension of grasslands and a frontier expansion that preceded Amazonian expansion—today it is mostly cattle ranching areas.

production that dominate the frontier remain unchanged. Intersectoral articulation models emphasize the conscious manipulation of institutions and policies, aligning the state with the existing economic interests in the Southeast, to maintain the existing agrarian structures in the frontier as a constant supply of raw materials at subsidized costs of family labor.

Oliveira (1972) observes that there is no incentive to modernize peasant forms of production since growing urban demand for agricultural products is met by the horizontal expansion of farming into new frontier lands. Thus, the continuous expansion of peasants into new frontier regions creates the conditions for the persistence of peasant forms of production and inhibits modernization of the small scale farming sector. The existence of an ever-expanding frontier to which to move becomes functional to the maintenance of peasant forms of production in previous frontier areas, now articulated and integrated into the national capitalist system of production. Moreover, the expansion of peasants into new frontier lands is not only functional for the appropriation of capital in the center southeastern regions of the country, but it is actively supported and encouraged by modern industrialization interests and their allies in the state.

In a post-frontier setting such as Rondônia, the intersectoral articulation model would predict the persistence of traditional production systems in an otherwise capitalist economy. Small landholders in the frontier would have gone from being mere subsistence farmers to producing agricultural commodities and cattle for the urban industrial sectors who would appropriate most of the value of the production. Agricultural production would be oriented to domestic urban markets, and therefore be based on diversified food crop production but with little technical improvement or intensification of production. On the other hand, cattle herding would be primarily for birthing, as described above. Young steers created in the frontier would be mostly produced for the cattle fattening sectors of the Center-East, where larger cattle ranchers would benefit from the production of cheap calves in the frontier regions. The increases in production levels are due not to increasing productivity but to the expansion of the area under production. While total production may increase due to further increase in the area under production, traditional forms of production and poverty levels associated with them are perpetuated in both frontier and post-frontier regions.

World Systems and dependency theories

World systems theories seek to explain frontier development and expansion as part of larger processes of global capitalist expansion and an international division of labor between the rich countries of “Global North” and the poor countries of the “Global South”. In this paradigm frontiers serve as a source of natural resources for international markets and are shaped by boom and bust cycles that follow the market demand for the extraction of these natural products. Based on dependency theories (Frank 1969; Wallerstein 1974; Amin 1977; Cardoso and Faletto, 1979), these theories conceptualize capitalist development as an interdependent process whereby some countries and regions acquire a predominant place within the world division of labor, using coercion to organize production elsewhere. The world division of labor becomes unequal and capital accumulation becomes concentrated in the large world cities through processes of “unequal exchange” in trade (Wallerstein 1974; Amin 1977). Peripheral regions, such as agricultural frontiers, become a source of cheap raw materials (Bunker 1985). Recent versions of world systems theories highlight a subordination of the peripheral regions towards the capital centers of the world that is grounded in the displacement of traditional economic production and consumption patterns by a capitalistic one while not necessarily being economically articulated to them (Knox and Taylor 1995).

Andre Gunder Frank (1969) is one of the early influential dependency theorists. Building on Paul Baran’s (1957) model of a metropolis-satellite structure of the capitalist system, Frank extends this model to Latin America. Specifically he uses this model to explain underdevelopment in Chile, Brazil and Mexico. The main argument of Frank across his work is that the underlying sources of underdevelopment are to be found in the persistent contradictions generated by capitalism throughout the history of capitalist development. These include the loss and misappropriation of economic surplus, the extension of this appropriation of surplus to the farthest reaches of society, the contradictions of uneven development and of international as well as national and regional polarization that this appropriation creates and the monopolistic nature of the structure of capitalism, which concentrates this appropriation in the major world metropolises.

Frank touches on several issues that are of foremost relevance to the agricultural frontier setting. In his analysis of Brazil, he contends that, unlike the assumptions embedded in development economics and traditional Marxist theoretical frameworks, there is no “dual economy” and the agricultural sector is not feudal or precapitalist, and has not been so since the colonial era. For Frank, frontier rural societies have never been isolated and closed but have always been part of the capitalist economic system. The concept of underdevelopment is inherently an outcome of economic development elsewhere, in which, poverty concentrates in the peripheral regions, especially in the agricultural frontiers. Thus, frontier regions are an inherent part of a single overall capitalist system, where underdevelopment processes in the periphery assure the concentration of power and resources in the large cities and metropolitan areas (Frank 1967).

Cardoso²⁵ and Faletto (1979), in an influential book about structural dependency in Latin America, stress the nature of these relationships between industrial world cities (core) and frontier regions (periphery). For these authors, structural dependency should aim to explain not only the interrelationships between classes and nation-states at the international global level, but also those internal to each country. Additionally, they find that the nature of dependency in the periphery is different from those countries in the core. While peripheral industries are established to create products that are mass consumed in the center, basic goods continue to be produced with traditional technology and maintain the original relations of production. Akin to “inter-sectoral theory”, dependency theory finds a functional role for the peasant masses in the frontier that serves to enhance income concentration in centers of capital accumulation without expanding the benefits of economic development to the periphery. Thus, the Latin American dependency school expanded earlier neo-marxist intersectoral articulation model of dependency to take into account also the different forms of relations that are created internally when the initial appropriation of capital by local bourgeoisie is tied to expatriate interests or with values and interests that are foreign in origin.

²⁵ Fernando Henrique Cardoso, one of the leading Latin American dependency theorists during the late 1960s and 1970s became President of Brazil in 1992 and was re-elected in 1996 with a center-left party but with an agenda that closely followed the neoliberal economic structural changes mandated by the IMF.

We conceive the relationship between external and internal forces as forming a complex whole whose structural links are not based on mere external forms of exploitation and coercion, but are rooted in coincidences of interests between local dominant classes and international ones, and on the other side, are challenged by locally dominated groups and classes (Cardoso and Faletto 1979: xvi).

This view expands the dependency model to include distinct regional social structures and political arrangements within dependent countries that, despite being subjugated to the global systems of exchange, struggle to influence how the commodities on which the global system depends will actually be extracted or produced.

Building upon the dependency school's emphasis on "endocolonialism", Stephen Bunker offers an innovative approach in which he argues in *Underdeveloping the Amazon* (1985) that the major constraint for developing the Amazon is in the nature of the extractive economies that predominate in this frontier region. These extractive economies do not encourage the formation of stable communities or local accumulation of capital and increasingly impoverish the environmental and social endowments of the frontier with each subsequent extractive cycle. Incapable of generating their own autonomous development, extractive frontier economies are doomed to bust.

Bunker adds to the Dependency School the thesis that the problem underscoring the development of Amazonia is not that the region depends on the extraction of natural resources, but on the nature of conventional economic theories that traditionally do not account for the "energy value" inherent in the resource extracted. Orthodox economic models emphasize instead the value accrued in the "labor" and "capital" invested in the production phase²⁶. The omission of "energy values" (presumably intrinsic to natural resource endowments) leads to the non-sustainable extraction of natural resources in the periphery and the accumulation of value in regions outside the ones from which the natural resources are extracted.

²⁶ Development economists have downplayed the importance of natural resource extraction in explaining modern economic development. Their economic analyses associate economic growth with a decreasing share of national product derived from and labor employed in the resource based sectors (mining, forestry, and agriculture). Agricultural economists also have downplayed the role of natural resources by attributing growth of productivity to improvements in the quality of labor, quantity of capital and technological change (Katzman 1987).

When natural resources are extracted from one regional ecosystem to be transformed and consumed in another, the resource-exporting region loses values that occur in its physical environment. These losses eventually decelerate the extractive region's economy, while the resource-consuming communities gain value and their economies accelerate (Bunker 1985: 22).

Bunker argues that this is an inherent limitation to adapting models created in "production-based" economies to explain the behavior of extractive economies. Most frontiers are "extractive-based" in Bunker's distinctive interpretation. These limitations, in part, expunge the dominant role played by the State in the other neo-marxist theories to a mere sideline roadshow, underlining the inadequacy of the modern state (bureaucracies designed to work in capitalist productive systems) to adapt to the realities of inherently extractive (frontier) economies.

Theories of value which focus exclusively on labor and capital do not simply err conceptually. Rather they reflect and legitimate a world view in which nature is subordinated to mankind and where natural resources are considered flow or income rather than part of a limited global stock or capital (Bunker 1985: 31).

Bunker uses concepts of entropy and energy creation and transformation as applied in economic analyses by Georgescu-Roegen (1975) to explain why value is accrued in the core as opposed to the periphery²⁷. Similar arguments have been established in the economics literature by Robert Costanza (1980) and Herman Daly (1980; 1986; 1997) to criticize conventional economic models that ignore the limitations of economic growth based on an unlimited supply of natural resources claiming the need to address flows of matter and energy in economic analysis. According to the position of Bunker and ecological economists like Costanza and Daly, the ruthless exploitation of natural resources in agricultural frontiers can be directly linked to conceptually ignoring the inherent "energy value" that is lost when these resources are extracted²⁸.

²⁷ The second (or entropy) law of thermodynamics holds that all physical processes reduce the availability of energy for further physical processes. When energy, which can also be thought of as stored work, is "used" it does not disappear, for that would violate the first law of thermodynamics, but it does change form so that it is less available for further work. For example, when coal is burned to produce electricity, the energy stored in the original coal is greater than the electricity produced, the difference released as heat that dissipates into the environment. The energy lost as heat is no longer available for work as in the original coal. Similarly, in an ecosystem, plants only convert 1 to 3 percent of the energy in the sunlight into chemical energy embodied in biomass. Energy from one trophic level to the next in the food chain is only about 10% efficient.

²⁸ It follows that accruing value to natural capital in conventional economic valuation systems would solve this problem. That is, an economy would become sustainable if net national product, measured as gross

More recent models of world system theories have challenged the articulation and dependency that is attributed to peripheral countries in relation to world cities (Armstrong and McGee 1985; Knox and Taylor 1995). In these analyses, instead of increasing dependency relations between periphery and core countries and cities, there is actually a divergence of economic dependence that is explained by processes of disarticulation of peripheral economies to the central core centers. However, cultural modes and capitalist modes of production are maintained and reproduced in the periphery, assuring their cultural and social dependence on the new capitalist modes of production and the newly-acquired consumer habits they are subject to.

In summary, world system theories predict Amazonian frontier regions will become a continuous source of raw materials and of expanding markets for products produced in the core regions. In this scenario, the post-frontier will be characterized by the exhaustion of the natural resources and the depletion of nutrient stocks in the soils. This eventually leads to a “hollow” frontier, as natural resources are mined out of the region and migrants move further along the frontier. Additionally, cultural modes of consumption from core regions are replicated in the frontier, securing the expansion of their markets and the underdevelopment processes in place in the region.

Household demographics and life cycles

Household life cycle theories use a demographic conceptual framework to explain the dynamics of frontier change. These theories share a common assumption that basic land use decisions are made at the household level, and it is the position of the household in its domestic life cycle that is a key factor in determining land use decisions. In the presence of weak market institutions, family labor is the critical factor determining the production capacity and consumption needs of the household. Frontier change, then, can be taken as the aggregate of individual household level decisions to the resources available, especially the critical factor: family labor.

output minus the monetary value of resource depletion and environmental degradation, is constant or increasing over time. However economists still hold to the substitutability principle, whereby modern technology eliminates all resource constraints to growth and development.

Theories that explain patterns of agricultural use based on household demographics and household development cycles can be traced back to Chayanov's household economic model. Chayanov wrote about small landholders' economic behavior in Russia at the turn of the century in conditions of land abundance similar to those found in Amazonia today.

Chayanov's theory of peasant behavior stresses the importance of family labor in shaping land use outcomes and strategies. Chayanov noted that households varied considerably in their size and that this had an effect over the type of crops produced and in the surplus accumulated. He explained this in terms of household structure, determining production by the availability of family labor and the degree of internal consumption. The main factors influencing this tradeoff between production and consumption are the size of the household, and its composition or demographic structure; that is the relation between working and non-working family members. This factor is summarized by the ratio of consumers to adult workers in the household or the consumer/worker ratio. Unlike a business or enterprise, a farm household is both a producer and a consumer, and it is this unique form of decision making that differentiates small landholders from other types of production units.

A second premise of Chayanov's thesis is the relationship between work and drudgery; in an economy where surplus production had limited value, drudgery was a high constraint on labor and increased exponentially as work is done. The household production level is determined by the intersection of this curve with that of the marginal utility of goods produced. In turn, marginal utility is determined by the standard of living, which is the amount necessary to support one consumer; the number of consumers each worker has to support (the consumer/worker ratio); the amount that has to be reinvested in the farm to maintain its production; and any other factors that require part of the farm's production.

Chayanov's household model departed from the prevailing concept of the rational peasant because of the imperfect markets for land and agricultural products that predominated in Russia during that period and his observations that peasants are not only driven by a profit maximizing behavior but more importantly include consumption goals. Consequently, his theory builds on the assumption that rural households lack

categories of price, capital, wages, interest, and rent and so have their own system of economic rationality, based on the balance of family need satisfaction and the drudgery of labor. These conditions seem to be far from the reality of the Amazonian frontier where the colonist households come from areas previously incorporated to the world economy and where selective sections of the Amazonian frontier are rapidly becoming absorbed into the regional and national Brazilian economy, and more recently to the global economy. Recent studies based on life cycle models merge Chayanov's theory with the household economy model, assuming markets exist for inputs such as labor, outputs such as agricultural products and off-farm work and capital (Barnum and Squire 1979; Singh, Squire and Stauss 1986; Walker et al. 2002).

Early Russian economists before Chayanov suggested that the heterogeneity of peasant farming systems was due to a "demographic differentiation" process as the family ages, thus setting the baseline for a household life cycle theory (Chayanov 1966; Thorner et al. 1966). Chayanov's contribution was to explain this heterogeneity over time (in his own words this heterogeneity described included "the type of buildings, the stock of equipment, the organization of draft, the measures to use these means of production, particularly the organization of labor in farms with few or many family members, even the crops grown, their money-earning power and sometimes the general trends of the farm" Thorner et al. 1966 p. 254) as a response to changes in the slope and position of the indifference curves between work and drudgery which in turn are defined by the production and consumption needs of the peasant farm.

The Chayanovian household life cycle model has been central in many recent studies of land cover and land use change in the Amazon with mixed results (Pichon 1996; Marquette 1998; McCracken et al 1999; Pan et al. 2004; Perz 2001; 2002; Moran et al. 2003). The Centro Agro-Ambiental do Tocantins presented an early conceptualization of how the concept of c/w ratio introduced by Chayanov is used to explain the domestic life cycle outcomes over land cover and land use change in the Amazonian context ([CAT 1992] In: Walker and Homma 1996). The process begins with the arrival of a young family which for convenience will consist of only two adult workers without children (c/w ration of 1.00). As the household grows in size as children are born, raising the consumption level and raising the c/w ratio, the crops raised will involve important

subsistence annual and semi-annual crops such as rice, beans, maize and cassava. As children age and can contribute to the work load, the c/w ratio declines, and the family is able to accumulate sufficient capital to invest in longer-term crops and economic strategies such as pasture for cattle. With the continuing growth of the family workforce and their participation in emerging local markets the household is able to expand their investments in cattle. The traditional system of slash-and-burn gives way to pasture formation spread with herbaceous groundcover.

Walker and Homma (1996) present an alternative model that can lead to the intensification of land use practices towards perennial crops in the latter life cycle stages. The model is similar in that it stresses that family responsibilities during the first years require production to be focused on subsistence crops that can be harvested in less than a year (i.e. rice, maize, manioc). Limited soil fertility, land abundance and lack of capital, requires that households open new forest areas every year to maintain subsistence production levels²⁹. As children grow and become part of the household labor force, production expands to include marketable perennial crops (i.e. coffee, cacao, palm trees) which can be sold for cash, monetizing small farmers into the market economy. Thus, from an initial phase of predominantly subsistence farming based on annual crops, increasing labor availability permits the household to move into a second phase, based on the production of perennial crops and the capitalization of the households into the market.

It is important at this point to review some of the characteristics of perennial crops that contrast them from the previously sown annual crops. Perennials usually do not enter into commercial production until four to seven years after planting (Walker and Homma 1996). Because of their susceptibility to insects, fungus, fires and changes in the market, perennials pose greater economic risk to the household than do annual crops or raising cattle. On the other hand, perennial crops offer environmental advantages over the other major land use classes because they provide a more stable forest cover, reduce erosion of soil nutrients and permit soil remediation processes in deforested areas (Serrão and Homma 1992; Pichon 1996). Also, since perennial crops require an intensification of land

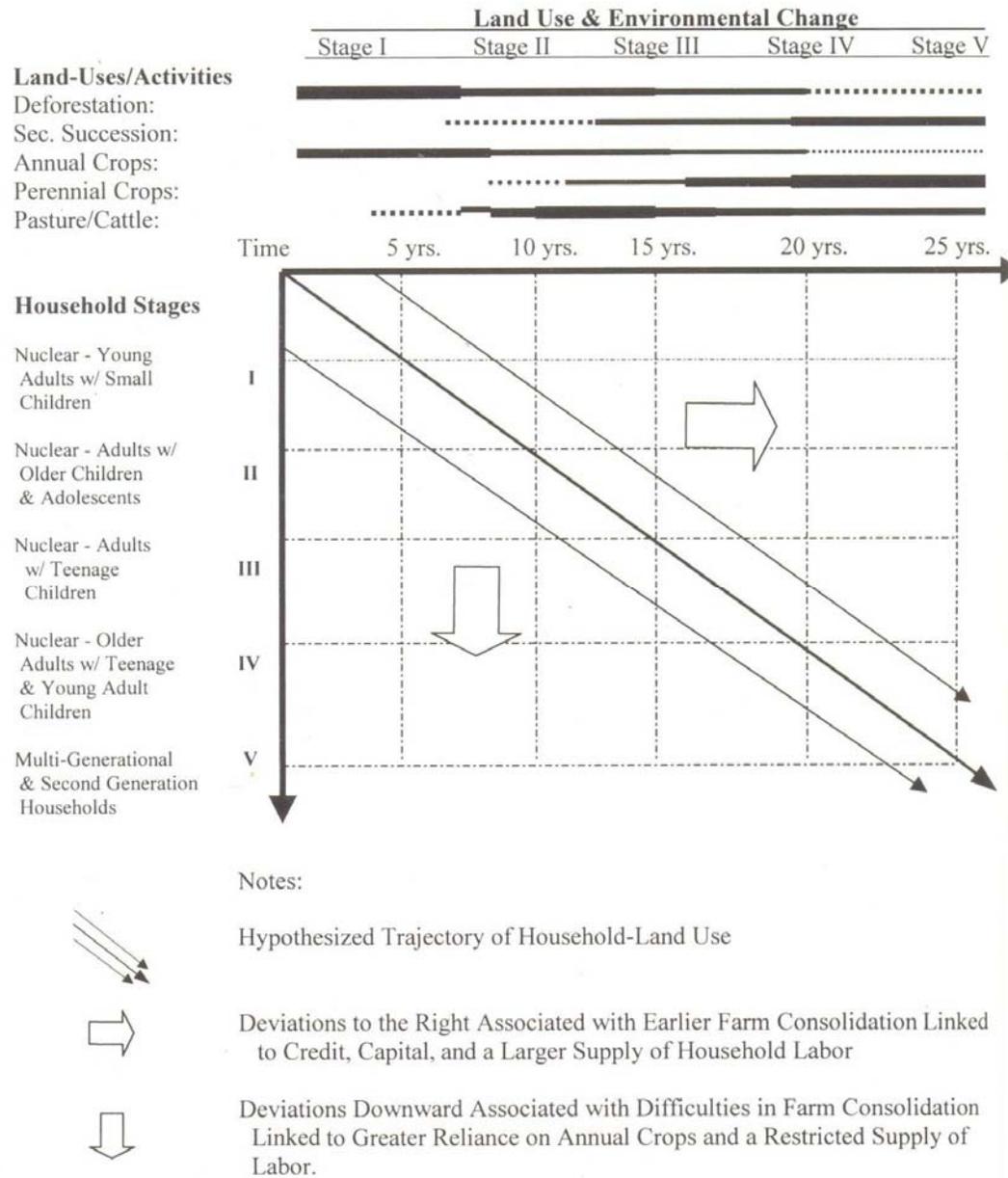
²⁹ In Rondônia, a previously forested site cleared by the slash and burn method can produce annual crops for two to three years before nutrient availability severely constrains further crop growth. Areas of lots that no longer sustain annual crop production are planted with perennial crops that, with proper care, can out-compete invasive weeds. Otherwise they are left to fallow or are continuously burned for pasture.

production and cyclically bring higher returns per hectare, it has also been argued that perennial crops can reduce deforestation elsewhere by concentrating production in already deforested areas (Reardon and Vosti 1995; Angelsen and Kaimowitz 2000; Vosti et al. 2001).

Unlike perennial crops, pasture is associated with more destructive land use practices since it is claimed it further depletes soil nutrient availability and requires extensive amounts of land in relation to other farming practices. Despite its negative environmental consequences and issues related to its long-term sustainability (Hecht 1993), cattle are associated with different medium- and long-term benefits for small landholders (i.e. low labor requirements, insurance function) (Hecht 1985; Browder 1988; Pichon 1996; Faminow 1998). As regional markets for beef and milk products have grown with urbanization (Faminow 1998) and international demand for Brazilian beef has increased (Kaimowitz et al. 2004), cattle have become an increasingly important source of income for aging small landholders.

The Anthropological Center for Training and Research on Global Environmental Change at Indiana University has summarized the household life-cycle model into a conceptual diagram (Figure 2.1.) that links the different life-cycle stages to the amount of land allocated to different land use classes (McCracken et al. 1999; Brondizio et al. 2002; Moran 2003; Moran et al. 2005). The model distinguishes five stages, where each stage corresponds to specific household level characteristics (duration of residence, household age structure). The upper portion of the diagram shows the different land use classes and the thickness of the line, the level of activity within each land use class over time. Each life-cycle stage (left-side y axis) is linked to a specific time frame within the life cycle and a combination of intensities of land use activities.

Figure 2.1. Conceptual framework of household transformations, land use and environmental change (McCracken et al. 1999)



These authors identify five stages households go through in a linear and sequential process. Each stage corresponds to a specific point in the household's

evolutionary trajectory determined by the composition and age structure of the family. In the initial stage (stage I) young parents with few children arrive at a newly opened frontier and rely on the production of annual crops for subsistence. In the second stage (5 to 10 years after initial arrival), households expand their area under annual crops, and perennial crops and newly formed pasture are established. Stage III (10 to 15 years after initial arrival) is characterized by an increase of available family labor as children reach teenage years reducing the emphasis on annual crops and expanding the areas under perennials and pasture. During this stage some of the areas that were previously used for annual crops are allowed to fallow in order to replenish soil quality for future use. In stage IV, between 15 and 20 years after initial arrival, when children reach young adulthood, ranching and perennial crops predominate and fallowing areas expand further. In stage V, after 20 years or more years, when children typically marry and migrate out of the household, perennial crop production and ranching continue to predominate and regrowth increases as more areas are allowed to fallow while some of the older fallows may revert into production.

McCracken et al. (1999; 2002) and Perz and Walker (2002) all point out several variables that serve to locate the position of the household along a life cycle continuum. These variables include duration of residence, age of household head(s), household composition, and dependency ratio. Duration of residence indicates the degree of a household's experience farming in the Amazon. A predictable pattern of farm evolution unfolds as farmers gain local experience and confidence over time (Moran 1989). Household composition - the number of elderly, number of working adults, and number of dependent children affects the households' capacity to manage a farm based on labor. Finally, dependency ratio is the ratio of dependents (children up to 16 years of age and elders older than 65 years of age) to working adults (males and females between 16 and 65 years of age).

Studies on household life cycles have usually been ambiguous about household and land use dynamics beyond the final stage. Perz (2002) considers two possible trajectories. The first follows that posited by McCracken et al. (1999), in which young adults decide to migrate to establish their own farms or seek employment in urban areas. This causes labor supply on the farm to decline, leading to a reduction of labor intensive

land uses (perennial crops) on the farm and the expansion of less labor demanding land uses, such as pasture. Labor constraints will also induce further fallowing of the land as old perennial crops are abandoned. For practical reasons in further discussion I will call this first trajectory the “empty nester” trajectory. A second trajectory proposed by Perz and Walker (2002) suggests a “generational transition” whereby the older generation passes control of the property to the children. These authors conclude that this is more likely where the young generation consists of couples with young children since the farm provides the security of an established productive estate. In this scenario, new clearings of primary and secondary forests increase to open up land for annual crops, reinitiating the life cycle. Of course this assumes the second generation will behave the same way as the first generation but preliminary data suggests these may not be so and is a question we explore in the subsequent chapters.

The household life-cycle theory has recently received wider attention in Amazonian frontier studies due to two main trends. The first has been the increasing accessibility of data, including surveys and remote sensing images that allow the examination of a large number of households and extensive areas, relating micro-level socioeconomic data with land-use outcomes. The second factor has been the need to look at the microlevel factors influencing land use decisions. With the reduction of direct institutional support to unsustainable land use practices (e.g., cattle ranching subsidies), policy analysis has shifted to the microlevel foundations of small landholders’ behavior in order to determine adequate policy changes to increasing deforestation levels in the Amazon.

A life-cycle stages approach characterizes the evolution of the frontier as the aggregation of household-level demographics. This dynamic aspect of the frontier, related to the family life-cycle, affects household composition, labor supply and consumer-worker ratios. The strength of life-cycle models lie in their ability to render dynamism, considering the temporal dimension of the household along its life-cycle to the traditional economic household models. Its limitation lies in assuming a similar progression in behavior across households for each stage of the life-cycle.

Frontier Stages

A variant of the household life cycle theory, frontier stages is analogous to the household life cycle but at a higher scale of analysis than the household, usually involving a whole frontier settlement region. Assuming that most small holder colonists arrive at a frontier about the same time and that most arrive when they are still in their early stages of their life cycle, based on the household life-cycle, different studies have proposed stylized stages that model how the social and environmental characteristics of a frontier develops over time.

One of the first studies that used the concept of frontier stages in the Amazonian region was Henkel (1982) who distinguished four stages of colonization; a pioneer stage, a commercialization stage, an abandonment stage and a consolidation stage and revitalization stage. The pioneer stage is characterized by the arrival of colonist farmers and their reliance on subsistence crops using land-extensive agricultural practices including long fallowing periods to recuperate soil fertility. With the improvement of road infrastructure a commercialization stage begins, allowing changes in land use from subsistence crops for commercial ones. The expansion into commercial production leads to faster forest conversion and shorter fallowing time, both of which contribute to declining soil fertility. The abandonment and consolidation stage is characterized by two parallel processes: (1) abandonment of lands by small landholders who are faced with decreasing soil fertility, land availability and labor scarcity; and (2) consolidation of abandoned lots by larger commercial interests, usually large cattle ranchers. As the frontier reaches closure and roads and larger capital interests settle-in a revitalization stage begins. This stage is characterized by the infusion of additional labor and technological improvements allowed by greater access to capital. The introduction of high-yielding tree crops may allow peasant to subsist in an otherwise capitalist frontier.

In another early example of the application of the frontier stages model, anthropologist Emilio Moran (1989) observed that the families in the Tranzamazon colonization projects who take advantage of secured property rights and existing infrastructure come in the latter stages of frontier development, differing from those who initially colonize the frontier. Moran contrasts the beneficiaries of frontier development as better educated, urbanized and with relatively good access to governmental and

financial markets as opposed to the pioneers who opened up the forest, which he characterizes as being poorly educated and ill-equipped to obtain credit and deal with modern institutions. Moran argues that whether spontaneous, directed or forced, all colonization processes go through diverse stages of adaptation based on the changing needs of the settlers. Therefore, the frontier process occurs in stages characterized first by the practice of past routines, followed by experimentation (success and failure) and eventually the emergence of improved agricultural practices.

Thiele (1993) builds up on Henkels' frontier stages model to describe the colonization process of another Bolivian Amazon region. The four stages described follow those of Henkel: a pioneer stage, an expanded production stage, a fallow crisis stage and finally an escape or production intensification stage. He notes that a decline stage is absent due to a very adaptive peasant sector that allows it to subsist despite declining soil fertility in their lots. Findley (1988) notes that in most Latin American frontiers, small farmers had great difficulty making the transition from the "pioneer" stage to a "consolidation" stage, whereby the farm becomes commercially viable. Therefore, Findley (1988) predicts a large outmigration from the frontier region in the intermediate stages and a reduced number of farmers in the latter stages of the frontier process.

In their early collaborative work, Browder and Godfrey (1990) posit an historical-geographical model of capitalist penetration where the frontier changes in a predictable linear manner through five distinct stages over time. Stages are characterized by the growth in the incoming population to the frontier, the consequent depletion of natural resource endowments, including forests and soils, and ultimately the increase of urbanization. As the frontier moves through these stages, increasing urbanization insinuates the rural realm in a more complex set of spatial and socio-economic relations.

A frontier stages approach suggests that the variations found among households in the agricultural frontier is a factor of the evolution over time of the farm and the frontier. Land cover and land use changes are the result of learning processes and of the structural conditions that affect frontiers over time such as urbanization, infrastructure development and soil nutrient depletion, adding a new layer of complexity to the household-level theory. While models based on different empirical studies and geographical regions vary

in the “stages” and strategies defined, they share a common deterministic theme of cycles or phases in experience, needs and resources of the household.

Both, the frontier stages models and the household life cycle theory, add a dynamic temporal element to agricultural household models; a small farmer households’ behavior is not the same at all times but changes throughout its life-cycle. However observations in the field led us to critique these models based on several flawed assumptions; (1) it assumes everybody arrives on the frontier at the same time, leading to a homogenous cohort of colonists, (2) is silent on the patterns of property subdivision and consolidation which are presently affecting almost a third of the properties, (3) it assumes a nuclear family household as the unit of analysis without considering the various non-filial land sharing (and labor compensating) joint tenure arrangements that farmers initiated during the early years following settlement, and (4) many different scenarios are possible under a “generational transition phase”, most of which do not involve a swift transition. Furthermore, as the frontier evolves, larger and more developed urban centers emerge with new economic and educational opportunities that blur the urban-rural divide (Browder and Godfrey 1990). Unlike the opening of new frontiers, the expansion of urban centers across the post-frontier creates new opportunities for rural and urban owners alike to expand their economic strategies in either domain. As the urban-rural interface becomes more blurry, urban centers become more influential in rural land use change processes (Browder 2001) accelerating property subdivisions and consolidations, as well as changes in property ownership. These observations and the background of other theoretical lenses lead to the revised household life-cycle model that is introduced at the end of this chapter.

Spatial economic theory

The spatial economics framework focuses on the regional processes of frontier expansion and land use change, emphasizing the operation of spatial and economic principles (e.g., relationship of producer distance to market and the marginal rates of return for different agricultural products) as defining the magnitude and timing of the expansion of the frontier and consequently, land use outcomes that prevail in different spatial regions. Spatial economic models rely on neoclassical economic growth theory

which views social change processes deterministically as a function of economic development from traditional to modern modes of production (Hoselitz 1961). They merge these economic principles with spatial principles of geography (e.g., central place theory, land-rent distance). The spatial economics perspective of frontier expansion tends to adopt a linear evolution model of change. Katzman (1977) recognizes that conventional conceptual frameworks of frontier movements, such as location and central-place theories, consider institutions as either given or irrelevant. Katzman's approach is to modify traditional location theory to take into account the political and institutional factors crucial to understanding changes in the spatial organization of the Brazilian economy. The author concludes that, despite these differences, spatial models that explain land use based on distance to markets are still very reliable in the Brazilian context.

Location theory integrates spatial concepts of geography with those of neoclassical economics. Neoclassical economics views the regional integration of frontiers through processes of market-directed flows of goods and factors of production. It takes major state intervention as given, exogenous and mostly negative to the relative function and welfare of the system. In the long run, this market-directed flow should lead to an equalization of welfare among regions, the lower the friction of distance between regions, the more rapid and complete the equalization process. Thus, it is not surprising to find that development strategies based on these models often emphasize investment in transportation infrastructure.

A central premise of spatial economic theory is that land-use is determined as a function of agricultural rents. Rent, the difference between the market value of agricultural products of a piece of land less production costs (capital, labor and inputs) and costs of shipping the output to market, determines the limits of commercial cultivation. A rent bid gradient relates the rent offered per hectare to distance from the market. The lower the marketing costs per ton-kilometer, the more extensive the frontier. Each crop has its own characteristic yield, production cost and marketing cost per ton-kilometer. Since marketing costs tend to vary directly with bulk, perishability and handling, each crop has its own rent-bid gradient with a unique slope and spatial limit of feasible commercial cultivation. Thus, at any distance, the crop that bids the most for the

land is cultivated. The spatial structure of a region is thus set by the rent-bid curves of the different crops for which commercial markets exist in a regional economy. Beyond the commercial frontier lies a zone of diversified subsistence farming.

Martin Katzman's review of the development projects sponsored by the government to colonize Amazonia is highly critical, claiming state intervention ignored many of the principles that underlie spatial economic theory. Katzman argues that the region's comparative advantage lies in economic activities that produce high value per unit weight and low transportation costs such as mining, cattle raising, lumbering or spice production, not in the cultivation of food crops associated with small farmer production systems. The author concludes that if the political willingness of the government is to help rural farmers in the Northeast, long-term solutions should include primary education, agricultural credit and technical assistance for small farmers and small industries. However he is skeptical, based on past experiences, of the political willingness to include such programs since they will not benefit the elite power structures in place and would impose considerable costs on them. Katzman's criticism contrasts with the view of other neoclassical economists who have analyzed the settlement and directed colonization programs of the Brazilian government during the '70s and '80s such as Ozorio de Almeida (1992 and 1995) and Andersen et al. (2001).

Anna Luisa Ozorio de Almeida studied five colonization projects in Mato Grosso and Southern Para, two of the oldest frontier regions in the Amazon (Ozorio de Almeida 1992). Despite the numerous problems that have plagued government directed-colonization projects during the 1970s, she concludes that Amazonian colonists are better off, compared to small landholders in other regions of Brazil, and have improved their economic well-being when compared to their initial condition. Ozorio de Almeida presents a rather optimistic outlook about the incorporation of agricultural fronts into the general economy of Brazil, whereby social conflicts and environmental costs are largely ignored. Instead, the Amazon territory is presented as gradually incorporating into the rest of the Brazilian economy. Changes in the organization of economic activities, work relations, agricultural technology and land tenure in the rest of the country have gradually caught up in the Amazon region. While these changes brought about the expulsion of large masses of the rural work force from the South and Southeast, the continuous

advance of the Amazon frontier permitted their location in these new regions. However, Ozorio de Almeida's study also shows how a purely economic analysis can hide the underlying social and environmental problems that characterized the opening of the Amazon.

In a more recent study using an econometric spatial analysis of a municipal level database of social and economic indicators, Andersen et al. (2002) argue that the development efforts in the Amazon have benefited the immense majority of the population and not just a few land speculators and local elites as early studies suggested. These researchers econometric analysis indicates that agricultural activities are increasingly being driven by local urban demand rather than governmental incentives. Urban population growth and urban income growth were found to be the significant explanatory variables for the growth of deforestation, the growth of rural GDP and the growth of cattle herds. Unlike expected, the construction of roads was found to be an increasingly endogenous process, even for federal and state roads. Urban population became the most important variable affecting paved roads in later years (1985-1995), while it was not significant in the earlier years (1980-1985). On the other hand, unpaved roads is also becoming an increasingly endogenous process, driven by the growth of the carrel herd and the level of rural GDP. The authors suggest that road building can promote sustainable land use practices if it improves infrastructure conditions in already settled areas (e.g. road paving in post-frontier regions), thus pushing land prices upward and lowering the prices of food products in urban areas.

Spatial economic theories are important for understanding the role of roads and markets in the larger processes of frontier settlement and evolution. However, on their own, they do not account for a complete understanding of the social and environmental processes occurring at the regional and micro-level. At the regional level, social and landscape changes in the Brazilian Amazon have eluded adequate explanation with existing theoretical frameworks based on conventional spatial economic principles (Browder and Godfrey 1997). Their more recent role has been their ability to complement agricultural household models (Walker et al. 2002) and *município* level models (Andersen et al. 2002) in order to account for a more complete picture of deforestation processes.

Contested and disarticulated frontiers—Post-structuralist framework

New directions in social science theories, drawing upon multiple disciplines, have influenced a more pluralistic and dynamic approach to understanding human and nature interactions. These are influenced by advances in ecological theories that suppress straightforward linear relationships between people and environmental processes. Instead, environments are dynamically and recursively created in nonlinear, nondeterministic and contingent ways, in which human behavior is an important, but not altogether predictable element. Therefore, “the very design of the transformed ecosystem is redolent of its social relations... created ecosystems tend to both instantiate and reflect ... the social systems that gave rise to them” (Harvey 1993: 27). In this regard, I find the structuration concept of Giddens (1984) useful, as it points to the continuous dynamic interplay between structure and agency, sedimented in space and time. Thus, new approaches to environmental change see agency as a key active player, not passive to the structural components of its environment (e.g., Long 2001).

An example of how agency affects land use change processes is presented by Marianne Schmink and Charles Wood (1992) in their book *Contested Frontiers in Amazonia*. They assert that instead of a single process of linear change, the confrontation between a diversity of social actors (peasants, indigenous people, miners, ranchers, church groups, entrepreneurs) competing for a variety of resources results in a diversity of contested frontiers with highly varied outcomes. By considering the diverse sources of power mobilized by these different actors at the regional, national and international levels, and by looking at these through case studies in the Brazilian state of Para, the authors demonstrate how violent confrontations characterize and shape the frontier economy and landscape in the Brazilian Amazon.

A second characteristic of more recent approaches to land use change studies has been the recognition of the plurality of factors that occur at different scales and their differentiated impact over the landscape in both space and time. In their book, *Rainforest Cities*, Browder and Godfrey (1997) present a pluralistic model of frontier expansion focusing on regional urbanization. Although designed to explain emerging patterns of urbanization in the Amazon that cannot be readily understood using traditional theories of spatial economics or world system theories, the disarticulated frontier urbanization theory

uses an underlying framework that can be applied to agricultural frontier settings, as well as to mining, populist and corporatist frontiers. The frontier is conceptualized as being disarticulated from the national Brazilian economy dissolving into a myriad of overlapping frontiers each evolving according to a distinct situational logic. This pluralism of local disarticulated frontiers has given rise to numerous types of social and land use configurations that complicate the task of understanding patterns apart from this process. One of the challenges of embracing the diversity and complexity of agricultural frontiers in the region will be to tease out the commonalities and threads of processes and factors that are characteristic of Amazonian frontiers through time to help improve our understanding of the frontiers and our potential to improve the outcome of frontier experiences in the near future.

An attempt to conceptualize the complexity of factors and processes that characterize agricultural frontier processes in the Amazon is presented by Charles Wood (2002). Wood developed a multileveled hierarchical model that attempts to organize these apparently disparate processes into a more coherent picture of the causes and consequences of land use change. In this model land use outcomes are the direct result of land use decisions made by households and firms, which in turn make their decisions within contexts that operate at higher levels. Drivers of land use change are characterized as either, socioeconomic drivers or biophysical drivers, and these are further divided in each subsystem into proximate (local level), intermediate (national/regional level) and distant (global level). The model allows to focus on the relationships that take place within each level, as well as the cross level dynamics that link one level to another. In the words of Charles Wood this is “not a testable theory in its own right, the models utility can be assessed in terms of its effectiveness as a guide to data collection and analysis, its ability of generate hypotheses that can be subjected to empirical test, and its capacity to organize information into a coherent understanding of how global, regional and local events are related” (Wood 2002 :7). The power of this model is its ability to organize in a hierarchical way the plethora of socioeconomic and biophysical factors and processes that impact land use change decisions at the household level while showing the interplay of numerous feedback effects across scales and types of drivers.

Post-structuralist frameworks recognize the importance on the one hand of agency and on the other of the interplay of social and biophysical factors at multiple scales. The recent image of Amazonia as a complex and dynamic interplay of multiplicity of actors and processes that are currently affecting land use change processes is giving way to new approaches to land use change studies that go beyond structural models or individualized rational models of economic behavior. I use these more recent approaches of environmental change studies to adapt the household life cycle theory to include these important aspects of scale and time for explaining land use change processes in the emerging Amazonian agricultural frontiers.

The household life-cycle theory revisited

As reviewed above, different theoretical lenses have been developed to explain smallholder farming practices in the Amazonian frontier, however, one of the most commonly used to examine land use changes at the farm-level has been the household life-cycle theory (Walker and Homma 1996; Pichon 1996; Marquette 1998; McCracken et al 1999; Brondizio et al. 1999). Although many of the recent versions of the household life-cycle models recognize the importance of exogenous factors in shaping land use outcomes, they still fall short of explaining the interplay between these factors and the demographic and socioeconomic household-level characteristics. I have presented above the flaws that support a revision of the conventional household life-cycle theory and the related frontier stages models. Based on notions from early frontier models (especially Sauers cultural successions), and from post-structural views of the importance of agency (local actors) and scale (hierarchical concept), I present an alternative household life-cycle model that considers a more dynamic understanding of land use change as conditioned by time, space and scale. This proposed model should take the present household life-cycle theory a step further into a more dynamic understanding of the effects of life-cycle variables over land use.

The model has two parts; the first addresses specifically the end of the household life-cycle and how it relates to changes in rural property ownership and property size changes. The second is more comprehensive and is based on two components; a temporal (successions) and a scalar one (hierarchies), both of which circumscribe the household

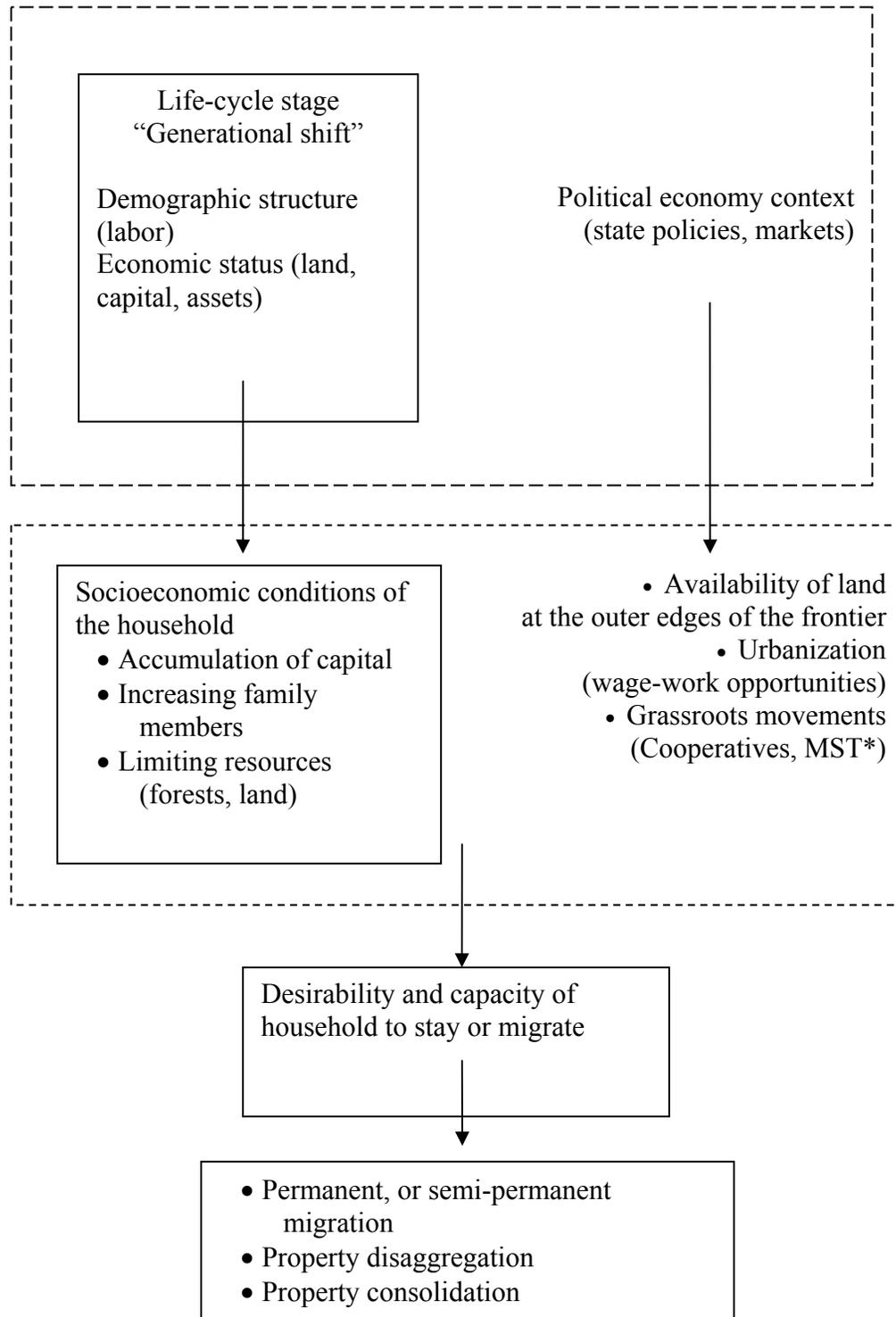
life cycle. The first component links the household life-cycle with the Sauerian concept of frontier successions or phases, and the second examines how it is linked with the concept of hierarchies.

Although conceptual models such as Charles Wood's hierarchical model (2002: 9) or Francisco Pichon's conceptual diagram (1997: 71) take into account the interrelationship between household-level characteristics and other contextual factors (e.g., institutional, biophysical), they are static models that do not consider the phases or successions through which a frontier goes through and in which the household life cycle is embedded within. This model attempts to go a step further by (1) considering a decision-making framework for the end of the household life-cycle, which we hypothesize is important for understanding property ownership and property size changes, and (2) a framework that explains the interplay between exogenous and demographic or endogenous factors over time. I first review how I am conceptualizing the end of the household life-cycle and its impact over changes in property size and property ownership.

The model assumes a conventional household life-cycle but considers the need of specifying property-level changes observed in the field. These changes refer specifically to property fragmentation and consolidation processes and property turnover, which I hypothesize, can be explained as an extension of the household life-cycle. As a household reaches the end of its life cycle, a new generation of families within the household requires land of its own (unless it migrates into one of the rising urban centers in the region). Regardless of how the household has managed its property in the past, it needs to cope with the increasing number of families within the household. The family will either split-up, with some members migrating out of the study site into new frontier regions or to an urban center, subdivide the existing property or, if it can afford it, acquire additional land. The decision of a household to aggregate, fragment or sell out is directly related to how it responds to or anticipates the end of its life cycle. Thus there is a direct link between the "generational shift", or the expectation of it, and changes in the land tenure and management arrangements within the property. Additionally, the "generational shift" can vary depending on whether the household head dies suddenly or gradually through illness and old age. How the household manages the transition, and its outcomes—

fragmentation, expansion or migration out of the region—is shaped by the following factors: (1) the relative success of the household in the past in managing its resources and accumulating wealth before it reaches the end of the life cycle; (2) the demographic structure of the family at the end of the life cycle, which is conditioned by the age and sex structure of the family minus any migrations outside of the household; and (3) the size of the property and the quality of the natural resource base that is left on the lot. This last factor is partly influenced by land use practices of the household during the previous stages of its life cycle. Large landholdings with improved pastures, large cattle stocks, productive perennial cash crops, and abundant forests are more prone to be cherished by the next generation than small fragments of a lot covered by degraded pastures and no additional forests from which to build a productive farm estate. A schematic drawing of the model described is presented on the left side of Figure 2.3. This model is tested in chapter 5 to see if the household life-cycle theory can in fact explain changes at the property level which have become increasingly important as the frontier ages.

Figure 2.2 Decision making framework of a household reaching the end of its life cycle



* Landless Rural Workers Movement [Movimento dos Trabalhadores Rurais Sem Terra]

The second part of the model looks at the interplay between exogenous factors and household life-cycle indicators over time. This model is used to test if in fact the household life-cycle model is important in explaining land use change processes over time. The concept of frontier successions or phases presented here is dissimilar to frontier stages models because, although, it recognizes that a frontier moves through a series of stages, these do not occur in a linear and predictable fashion. Instead, contextual features, such as the social profile of the settlers, the history of the settlement process or its articulation to other regional markets, determine the rate and characteristics of these phases. However, I do acknowledge that there is a series of successions or phases through which frontiers move; from a somewhat autarchic economy to one that is increasingly articulated to a regional market economy, and presumably, in different degrees and forms, to different types of global forces.

An alternative model presented earlier (figure 2.1) portrays frontier stages and household life-cycle stages as occurring parallel to each other. By simultaneously linking the household life cycle to the concept of frontier stages it assumes that the frontier moves through stages in a similar time frame and linear progressive nature as the biological life cycle of a household. My model considers both as independent processes. I adopt the earlier concept of the frontier as a series of successions or phases as a way of incorporating a temporal layer to frontier processes that is broader in scope than the one that circumscribes the household life-cycle model. This temporal dimension is not characterized by predictable linear stages like the life cycle of a family (since a household's life cycle is determined by the biological cycle of the household head), but instead depends on social and economic factors that are much more complex and unpredictable than the life cycle of a household (also considering that the frontier can be stagnant or retract over long periods of time – including many household life cycle generations³⁰). Although there is no linear and predictable path that the frontier goes through, as presented in frontier stages models, the frontier does move through successions or phases that are instead guided by contextual features beyond the frontier

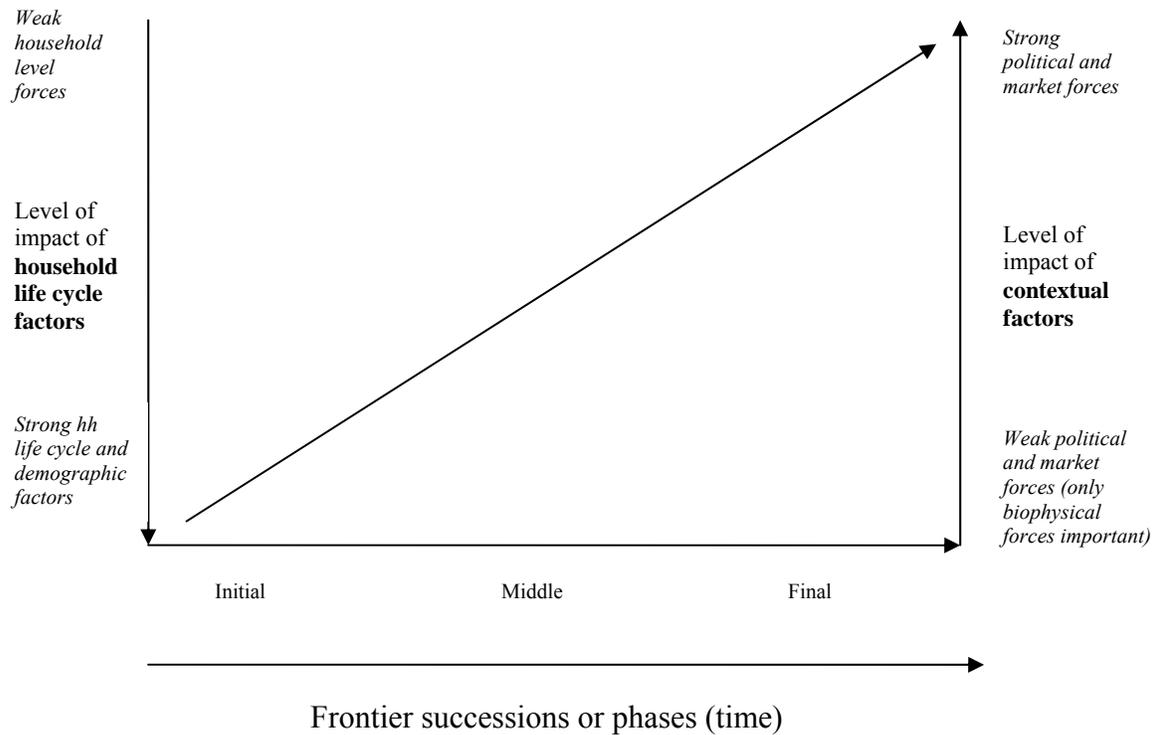
³⁰ The idea of agricultural frontiers in the Brazilian Amazon stagnating or even retracting after an initial expansion has been elaborated comprehensively by Donald Sawyer (1984) and Stephen Bunker (1985).

space, by the physical characteristics of the place and the cultural background that settlers bring with them to the frontier³¹.

Although conventional models are useful for linking household life cycle variables to land use change processes, I contend there is another temporal dimension or layer defined as the progression (and possibly retraction) of frontier successions or phases that conditions the power of the explanatory variables at the household level. Despite its local variations, over time the frontier will become less and less autarchic and more and more articulated with regional and global processes. This temporal layer therefore is important for understanding the changing relationships between the factors that can explain land use change outcomes. A graphical representation of the relationships between household life cycle factors, contextual factors as shaped by regional and global processes and the concept of frontier successions or phases is presented in figure 2.4.

³¹ A study presented by Simmons et al. 2007 that empirically tests if violence in the Amazon is place specific or intrinsic to all frontier processes concludes that it is particular historical relationships of violence between different actors (in this case small and large landholders) in the frontier that have given rise to places with high levels of violence, where actors become convinced that a repertoire of aggression and self-defense are necessary for survival, thus recreating violence over time. Therefore the high levels of violence reported in the south of Para, Brazil, are place specific and not a recurrent theme throughout frontier regions thus supporting the model presented here.

Figure 2.3 Dynamic conceptual model of the inverse relationship between impacts of household life cycle factors and those of contextual factors (markets, policies) over time (frontier successions) for explaining land use.



Regardless of the type of impact that the combination of household level factors and contextual forces have on household land use, the model stresses the inverse relationship between the two kinds of factors over time; the inverse relationship is therefore a function of the successions or phases through which the frontier evolves. It implies that household life-cycle variables impact over land use will be strongest in the initial phases of the frontier process and will weaken as the frontier moves from a more autarchic context to one that is more articulated with regional and global factors. In contrast, as the frontier evolves, contextual forces, such as the market and local politics, will progressively increase their impact on land use strategies at the household level. The final phases of the frontier, as is the case of present-day Rondônia, will see a convergence of land use strategies as these forces become increasingly influential in shaping land use strategies. As the frontier closes in, households become more reliant on markets for survival and less dependent on family labor, limiting the explanatory power of

demographic variables over time. Households that are not able to adapt to the new post-frontier context become more susceptible to sell-out and migrate towards new frontier regions. I interpret the widespread adoption of cattle ranching and the conversion of fallows into pasture, as part of this post-frontier homogenization process of land use practices among households.

However, while there is a tendency towards similar land use strategies across households over time, at a regional level, there is a tendency towards the diversification of frontier processes across regions. That is, as frontiers evolve they will create their own dynamics depending on the history of the settlement, the ecological and biophysical characteristics of the region, their articulation with other economic centers, etc. In short, as different frontier sites move through the various stages they will become increasingly differentiated despite similar initial conditions.

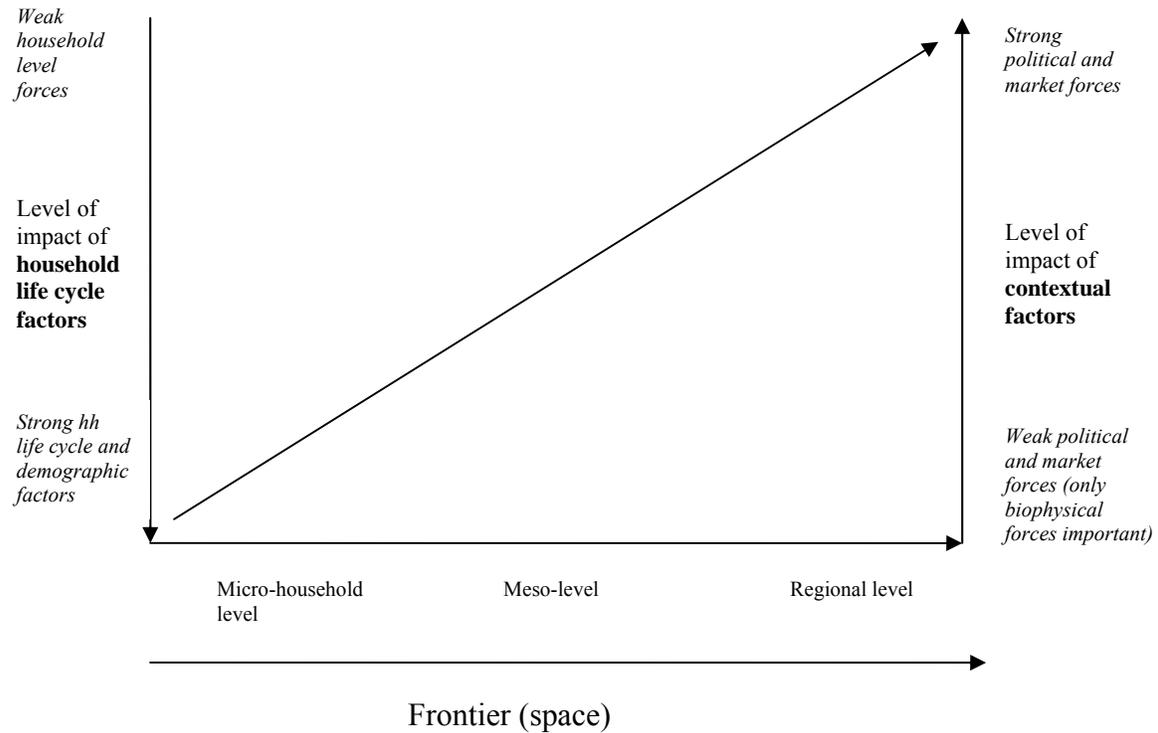
This has important implications for land use and land cover processes at the household level. Regional factors and processes can mediate, or contest, forces and factors that come from higher levels, such as national policies or global markets. On the other hand, regional factors also hold the range or latitude of decision-making processes at the household level. Here I consider two examples of the increasing importance of regional, or meso-level factors that impact land use change strategies; (1) the type of urban-rural interface that develops in the region, and (2) the local capacity of social groups to contest local elites' economic interests and promote alternative types of development than those imposed by local elites.

The urban-rural interface, more than a spatial concept, is the space where social networks and the various flows they promote (e.g., financial capital, social capital, labor, technology, and information flows) interact with exogenous forces (public policies, macroeconomic conditions) and endogenous processes (e.g. population density, cultural background). Therefore, the type of urban-rural interface that develops in a particular site will shape how small landholders view and interact with the outside world. The complexity of arrangements possible and the historical interrelations between factors will inevitably form distinct regional characteristics that will promote different land use and land cover processes at the regional scale.

Another example of regional trends that shape land use change processes is the level of social capital that has developed regionally among small landholders. Social capital is defined as the networks or values and trust or commitment present in a group or community (Coleman 1988; Putnam 1993). Manifestations of social capital vary from acts of reciprocity to social organizations such as churches and sports clubs. Therefore social capital becomes important to explore the capacity the local population acquired over time to organize and to respond to external forces. Recent literature in natural resource management identifies the importance of social networks and forms of association in impacting the way state and markets operate locally (Bebbington 1997; Hall 2000; Colfer and Byron 2001;). It follows that social capital can be an important factor affecting processes of land use and land cover.

Both, the urban-rural interface and social capital are used as examples of a wider range of meso-level factors that contribute to differentiate frontier processes at the regional level. Figure 2.5 presents the second component of the model that I present in this dissertation, showing the impacts of contextual factors at different spatial scales and how they compare to the power of life-cycle variables. I follow the observation of Pan et al. (2005) that land use change models have concentrated more on each side of the spectrum- the household life cycle indicators and macro-level processes, but not on the meso-scale factors, such as the urban-rural interface and social capital, without which models do not completely capture the range of factors and relationships impacting land use change processes.

Figure 2.4 Dynamic conceptual model of the inverse relationship between the impacts of household life cycle factors and those from contextual factors (markets, policies) at different spatial scales for explaining land use.



There are two reasons for considering scale in land use change studies; (1) most natural resources management problems, including land use and land cover change processes, require looking at the interlinkages beyond the confines of a local system, and (2) factors identified on one scale are not the same, nor do they behave the same way as those operating on another scale. In the first case, the concept comes from landscape and ecosystem studies, whereby the connectivity between components and the interrelations among processes within the ecosystem are crucial for understanding the ecosystem itself. In this case the same applies for land use and land cover change processes. For example, the conversion of forested regions to other land cover classes can dry out streams and rivers that cut across the parcels of small landholders living downstream, hence the need to study land use change processes beyond the confines of a lot or even a settlement project. An example from this dissertation shows land use change decisions are being

influenced by the opening of new frontier regions hundreds of kilometers away, causing landholders in our study sites to overstock pasture areas to later move part of the herds when pasture becomes ready in the new frontier regions. In the second case, the point is that one cannot assume that the factors operating at one scale behave or remain the same when operating at another scale. That is, macro-scale systems cannot be simplified as representing the sum of all household level processes, nor can the household level system be considered a mere microcosm of large-scale systems. An example from this dissertation showed that the distance from the farm to the major urban center did not significantly affect land use strategies between households while studies examining this variable at the regional scale, for example among municipalities, found it is the single most important factor influencing land use strategies (e.g., Andersen et al. 2002; Mertens et al. 2004).

This section of the dissertation has presented a revised household life cycle theoretical framework that attempts to take into account the relationships between household life cycle variables and contextual factors affecting land use change processes over time (figure 2.4) and spatial scales (figure 2.5). This revised framework, developed from other theoretical approaches, will allow specifying more appropriate studies for understanding the role of household level factors over land use change processes when using the household life cycle theory.

Conclusions

Frontier theories attempt to explain the processes of social and environmental change that characterize the settlement of new lands. The last of these frontier scenarios has been the Amazonian frontier. This chapter reviewed the main theoretical works that have conceptualized the processes of frontier expansion in Amazonia, which include capitalist penetration, inter-sectoral articulation, world systems, household life-cycle, frontier stages, spatial economics and disarticulated development theories. Although the Turnerian frontier thesis has informed current work in Amazonia (and the process itself), Amazonian scholars have emphasized different aspects of the frontier expansion process. Political ecologists emphasize the dialectical confrontation between peasants and capitalists, life-cycle theories have been more interested in the dynamic process of the life

cycle in shaping the landscape, spatial economics in the regional effects of roads and markets and pluralistic disarticulated frontiers in the plurality of the frontier types that have emerged. The impact that life-cycle theories have had on agricultural household models in the Amazon is an important trend in current studies of land use and land cover change. The conceptualization of frontiers as moving in stages that are determined by the life cycle of the household is gaining wide acceptance among modelers and researchers of land use change in the Amazon. This dissertation will attempt to analytically measure the importance and relevance of the household life cycle in the Amazonian frontier using empirical data from Rondônia, Brazil. I use a revised model of the household life cycle theory to be able to test for household life cycle variables while considering important additional concepts from newer theoretical approaches. The next chapter describes how data has been obtained and the research questions and hypotheses that guide this study.

CHAPTER 3

RESEARCH METHODS, STUDY SITES and HYPOTHESES

Background

The research for this dissertation builds on data collected as part of a larger research project on land use strategies among small landholder farmers in the Amazon region³². A description of the larger project is found in chapter 1. Trained as a tropical forester, my interest in social science theories of frontier development led to the cross-disciplinary structure of this dissertation and the questions it addresses. Social science theories that attempt to explain the process of frontier development were discussed in Chapter 2. Acknowledging the recent resurgence of interest in household demographic life-cycle theories in Amazonian land-use literature, the research questions, hypotheses and analyses focus on the household life-cycle thesis. An in-depth testing of the life-cycle theory provides insights on the conceptualization of frontier space and the relevance of past and present frontier theories.

In 1992, with a grant from the John and Teresa Heinz Charitable Trust, Dr. John O. Browder inaugurated a 7-year pilot project to demonstrate alternative farming strategies among a sample of small farmers in Rondônia, called the “Rondônia Agroforestry Pilot Project” (RAPP). As part of the initial participant selection screening for the RAPP, 240 farmers in 3 *municípios* of Rondônia were interviewed by a team of trained Brazilian university students using a standardized questionnaire. While only 50 farms were selected to participate in RAPP, the survey data from all 240 households provides the baseline data for this dissertation.

In 2002, with a grant from the National Science Foundation (cited above), Browder and co-PIs Walker and Wynne, directed new research teams, the one in Rondônia being coordinated by Dr. Marcos A. Pedlowski of the Universidade Estadual de Norte Fluminense, and revisited the same 240 properties, resulting in 281 completed

³² National Science Foundation (NSF) project: Dr. John O. Browder, Dr. Robert T. Walker, and Dr. Randolph H. Wynne. Patterns and processes of landscape change in the Brazilian Amazon: a longitudinal comparative analysis of smallholder land use decision-making. NSF grant #BCS-0136965, 2002.

questionnaires due to property subdivision occurring since the 1992 baseline survey. The 2002 survey instrument was based on the 1992 questionnaire to provide a set of benchmark variables that would enable a systematic longitudinal comparison of changes occurring on the same property over this 10-year period. The resulting panel data provides what best I know as the first and only longitudinal survey of the same properties over a 10-year period ever conducted in Rondônia. The 2002 survey also provided important new insights into processes of land use change in the Amazon that would lead to a follow-up study of a sub-sample of 80 farmers in 2003. My role during the 2002 field survey was to enter freshly collected survey data and ensure validity checks for surveys while still in the field. It also included a preliminary test for designing a qualitative methodology to reconstruct historical changes in land use at the farm level (hereafter referred to as land-use pathways) undertaken in July-August 2003.

In June-August 2003, a detailed qualitative follow-up survey of 80 farmers was undertaken in all three study sites. Data collection methods included semi-structured interviews and land-use pathway reconstructions. During this second field trip I coordinated the field research team. The field work entailed in both the 2002 and 2003 surveys is delineated in the next section

Study Sites and Household Sampling Selection

Data collection was undertaken in three distinct settlement projects separated from each other by approximately 200 kilometers (figure 3.1). The three study sites selected (Rolim de Moura, Nova União, and Alto Paraiso) were settled at roughly the same time (between 1977 and 1983), are equidistant (approximately 60 kilometers) from the main highway bisecting the state of Rondônia (BR 364), and represent the range of settlement conditions found across the state. The main biophysical and social characteristics of the study sites are summarized in Table 3.1. Each study site was divided into equal size road sections (7-10 km) containing between 20 and 30 property lots. Three road sections were randomly chosen from all possible road sections within each study site. All property owners within each road segment selected were interviewed in 1992 and 2002. In both surveys the male and female household heads were interviewed by trained Brazilian researchers using a standardized 18-page questionnaire. The 2002

survey was based on the 1992 instrument with several questions added to reflect changes in conditions since 1992.

Figure 3.1. Settlement areas and study sites in the state of Rondônia, Brazil.

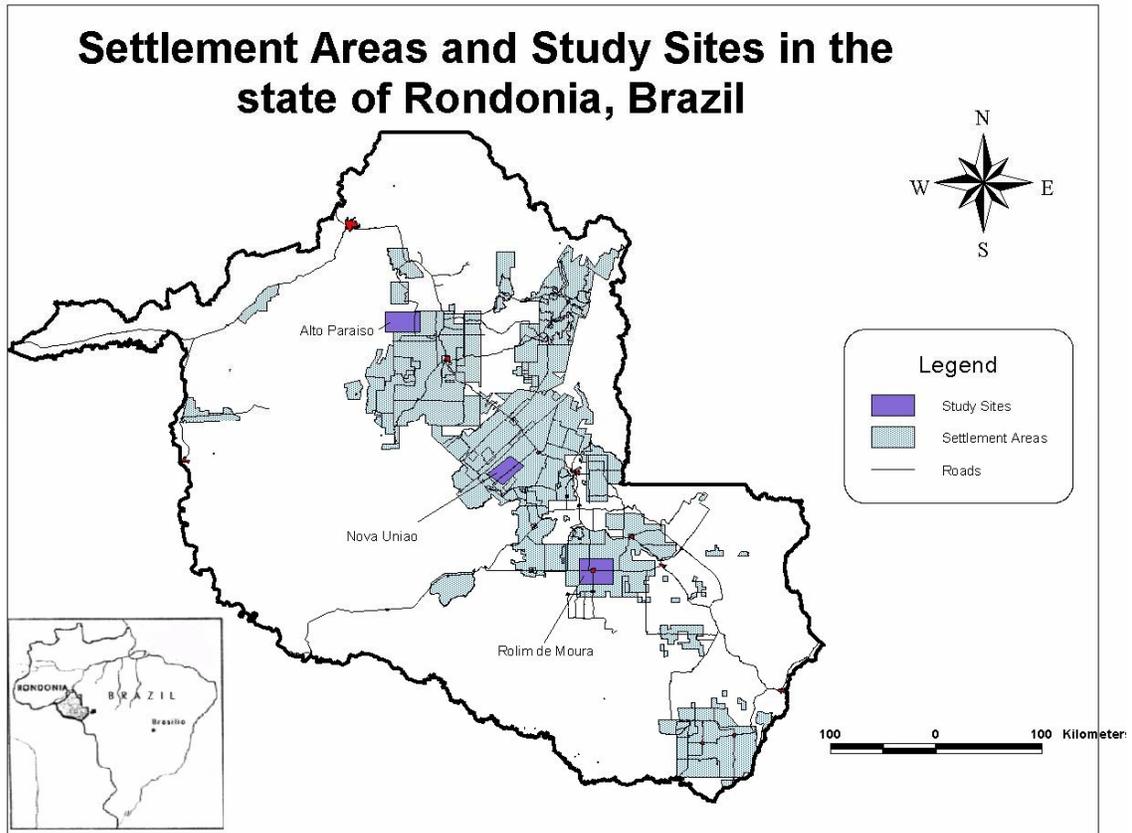


Table 3.1 Characteristics of project study sites in Rondônia (1992 and 2002)

Characteristic	Nova União	Alto Paraiso	Rolim de Moura
Location	62°35'Wx10°50'S	63°20'Wx9°35'S	62°47'Wx11°40'S
Altitude ³³	100-225	110-369	250
Average annual rainfall (mm)	1600-1700	2000-2100	2000-2250
Main soil type ³⁴	PE 3/Re ³⁵	Pva 13/Rd 3 ³⁶	PE 9/Ce 23 ³⁷
Vegetation cover	TTSMF ³⁸	TTSMF	TTSMF
Sample size (1992)	97	82	61
Sample size (2002)	112	114	55

Field Work

Field work was undertaken in the southwestern Brazilian state of Rondônia during two consecutive years, 2002 and 2003. During both, the 2002 and 2003 trips, secondary data ranging from agricultural prices, crop and cattle production statistics by municipality and regional maps, among other relevant information, were collected in the main state and federal agency offices in Rondônia. Contextual information of regional changes were explored through informal conversations with local personnel working in NGOs, the state university and rural extension agencies and other key informants.

The 2002 field research entailed a comprehensive household level survey, ground-truthing main land cover classes, informal interviews with key informants and organizations, and archival work in the study sites and in Porto Velho, the capital city of the state of Rondônia. A detailed review of the survey and the sampling method used is described below. Ground-truthing of main land cover classes was done with a Geographic

³³ Meters above sea level (IBGE, Elevation maps, 1974)

³⁴ Projeto Radambrasil. Mapa Exploratório de Solos, 1:1000,000, 1979.

³⁵ Eutrophic yellow-red podsols with patches of eutrophic litolic soils.

³⁶ Alic yellow-red podsols with patches of dystrophic litolic soils.

³⁷ Eutrophic yellow-red podsols and non-hydromorphic cambisols.

³⁸ Transitional tropical seasonal moist forest.

Positioning System (GPS) and integrated to a Geographic Information System (GIS) system in Blacksburg. Key informants included governmental officials, university professors, independent researchers and members of NGOs working in the study sites with rural and agricultural development. Archival work included reviewing government documents, published materials about the region and secondary sources found in development and agricultural research agencies.

Household Surveys and other methodological tools

A standardized questionnaire was administered to the stratified random sample of 240 selected properties described above, during June and July of 2002. If the lot had changed ownership since 1992, the questionnaire was administered to the new owner. If the lot was subdivided, the survey was administered separately for each one of the new and old property owners (this is why in 2002, instead of 240 households, 281 had to be interviewed). The household level surveys included questions on land use and land cover types (e.g., pasture, perennial crops, annual crops, primary forest, secondary growth, etc.) as well as demographic and socioeconomic characteristics of the household, timber and non-timber forest product extraction, assets, credit, participation in wage labor, participation in social organizations, ownership of urban properties and future aspirations. Both 1992 and 2002 questionnaires assumed that the household was the main unit of production. Questions were originally designed in 1992 to link land cover classes with agricultural production and socioeconomic characteristics of the household. In addition to the questionnaire, a map to scale was drawn with the farmer on the spatial location and size of different land cover types within his or her property. GPS coordinates collected in the field included the house and property boundaries of each property surveyed, and selected land cover types within each property, used in subsequent geo-referencing and ground-truthing, as well as land-cover classification tests. These data (survey data, land cover types, and property boundaries) were integrated with Landsat TM satellite images to create a GIS grid for subsequent analysis of land cover changes within each household plot for each year of the entire study period (1992–2002).

The 2003 field work sought to reconstruct historic land use and land cover change events that occurred at the farm level for the previous ten years and link them with the

decision-making rationale of the household. A stratified random sampling protocol was used to select a subgroup of properties (n=80) for this study from the total surveyed in 2002 (n=281). Preliminary analyses of the survey data collected during the two previous field trips showed subgroups of farmers behave differently depending on whether they were new or original landowner farmers and if they were aggregating properties, fragmenting the size of their landholdings or remaining stable. The sampling process randomly selected households from each one of these groups but purposely over-sampled properties that maintained the same size and were being managed by the same household as in 1992. This was done in order to secure a large enough sample that spans the entire ten year period without major shifts in the size of their property or ownership status.

Once in the field, the methodology combined semi-structured interviews with participatory mapping techniques to reconstruct land-use pathways over time. The methodology had three parts in this order; (1) mapping to scale of the extent and distribution of the different land cover types within the farmer's property, (2) reconstruction of land use change events over time for the last ten years, and (3) a semi-structured interview to determine the context and reasons for major land use change events and strategies. The baseline (1992) map was a sketch of the boundaries of the original 100 ha plot, laid out in relation to the main feeder road and showing major streams and rivers that cross the landscape. Landsat TM images, registered to each property in the sample frame were printed-out for each farm for each year and were used to situate the farmer's lot and recall spatially where and when major land use change events took place and the year of occurrence. Maps of all properties covered during the surveys in 1992 and 2002 were available due to GPS points collected during the survey field work and plotted over the satellite images as a GIS shapefile layer. Once the interviewees understood the scale of the drawing and were familiar with the satellite images, a systematic recollection of land use change events by year starting in 2002 and moving backwards in time was done with the farmer. Land use change events were marked over the printed satellite images and recorded in a spreadsheet designed for this mapping exercise. The spreadsheet reconstructs the historical pathway of present land cover classes through previous land use classes and backwards in time until 1992. Columns represent years and lines represent the different spatial plots of land use. Each

land-cover change event was followed by a systematic review of possible reasons that guided or affected the land use decision-making processes.

The land use pathway and mapping exercise were followed by a semi-structured interview that included questions on the history of cattle herds on the lot, credit history, fallow management, changes in property size, migration of family members, and forest extraction and tree planting practices within the farm property over the 1992-2002 period. The questions were designed to inform reasons for land cover change and to cover information gaps during the 2002 household survey. Extensive walks through many of these properties served to identify land cover types at the ground level, at which GPS coordinates were collected for subsequent satellite image registration and analysis and to corroborate the information collected during the survey, interview and mapping process.

At this point it is important to discuss some of the limitations of the methodology in relation to the quality of the data collected. Especially important is the accuracy of the maps drawn with the farmers and their recollections of past events. This depends on the knowledge of the owner about her or his property and his or her ability to estimate these parameters spatially and temporally during the mapping exercise. Some owners were not present and in that case, the interviewer relied on only one of the family household heads (spouse or son), thus getting only partial information. In a few cases the owner was not as familiar or able to respond to the questions due to lack of familiarity with scales and maps, or because she or he was new and unfamiliar with the property. Although interviewers were trained in the mapping exercise, the quality of the maps also varied in relation to the ability of the interviewer to engage the farmers in the mapping process, and to translate the farmers' answers onto the map at the appropriate scale and in the appropriate area on the map relative to its real physical location. Final maps had to rely not only on the information collected in the field with the farmer but had to be correlated with interpretations of satellite images that could help refine land cover extensions spatially and land cover changes temporally. All interviews, of course, were conducted in the Portuguese language.

The following sections review the research questions and hypotheses of this dissertation.

Research Questions and Hypotheses

This dissertation provides a case study analysis of social and environmental changes in the landscape as a small holder agricultural frontier gradually gives way to an emerging post-frontier in the Amazonian state of Rondônia, Brazil. It does this by examining changes at the lot level for the following; (1) property fragmentation and expansion, (2) property ownership changes, and (3) land use and land cover changes. The purpose of this dissertation is to empirically test if the household life-cycle theory can explain these changing socioeconomic and environmental characteristics of the landscape as it moves from a frontier scenario to a post-frontier. How well does the household life-cycle theory explain patterns and processes of land use and social change on the Amazonian frontier? Are properties fragmenting, expanding or consolidating as households reach the end of their life-cycle? Are small holder farmers who initially settle able to persist in the emerging post-frontier? What are the land use strategies that small landholders adopt as they move from a frontier to a post-frontier? Are these related to the characteristics of an aging household or to exogenous forces? In short, is the household life-cycle theory still relevant for explaining social and environmental changes in the post-frontier? Previous work has concentrated on the initial stages of the frontier process and has speculated about the social and environmental consequences of predominant trends. As we move into a post-frontier context and the original households reach the end of their household life cycle we are in a unique position to empirically test this theory in light of the actual trends that we find in the post-frontier today.

The overall hypothesis of the dissertation is that emerging trends in land use and land cover in the Amazonian post-frontier can be adequately explained by the changing demographic structure of the household life cycle. New trends important for understanding land use change processes such the fragmentation and consolidation of properties and property ownership changes are also tested. The alternative hypothesis would be that the evolving post-frontier landscape cannot be significantly explained by life-cycle variables and is instead the result of other variables such as the socioeconomic characteristics of the household, institutional factors, capital assets, biophysical characteristics of the lot, among others. Also, important concepts from other theoretical models, such as the notion of frontier successions or phases and hierarchical scales, can

be adapted to help explain when and how household life-cycle variables are more relevant in explaining land use change processes.

The following questions are not research questions to be empirically tested in this study but are questions unresolved in the literature, which this study hopes to inform and contribute to and which guide most of the discussion preceding and following our analysis of the research questions outlined above:

Are smallholder farmer forms of production a viable and sustainable development option for Amazonia?

What have been the lessons of directed colonization planning schemes for regional and development planning?

What are the mechanisms through which rainforest conservation can be promoted at the small landholder level?

Can frontier land use intensification practices stabilize deforestation rates and reduce encroachment on biodiversity “hot spots” and protected areas?

I review how the findings of this dissertation contribute to the ongoing debates of these questions above in the concluding chapter.

The Dependent variables:

The dependent or outcome variables to be tested correspond to the three types of outcomes we hypothesize are determined by the household life-cycle model and the indicators that specify these outcomes. These are; (1) property ownership, (2) property size, and (3) land use and land cover classes.

Property ownership is conceptualized as occurring in one of three forms, (1) the household is stable and no ownership changes occurred during the study period, (2) the household head(s) passed away during the study period and a new household took over the management of the lot (“generational transition”), and (3) the household sells the lot and migrates out of the region, passing the management of the household to a new household. The study used two subsamples depending on the year of the survey. The 1992 subsample classifies households as (1) stable, (2) “generational transition”, and (3) “sold-out” household. The 2002 subsample classifies households as (1) old farmer, if they

have remained in the lot in 1992 and 2002, (2) new farmer-related, if the household head is one of the sons or daughters of the original owner interviewed in 1992, and (3) new farmer unrelated, if the farmer is a new household in the sample of 2002 for a property sampled in 1992.

Property size is conceptualized in two ways. The first dataset uses the property as the unit of analysis and the sample is made up of three types of properties. Properties are either stable, fragment or expand. The second dataset uses the household (owner) as the unit of analysis. In this case a household is either stable, disaggregates its landholdings (sells part of its land), aggregates (consolidates additional land independent of where), or sells off all his landholdings during the study period. Property size is also operationalized as a change in the size of the property and estimating the change in size in hectares.

The third set of dependent or outcome variables are classified in one of five categories of land cover classes: annual crops, perennial crops, secondary growth, pasture and forest. Land cover classes are all measured in hectares. These are described in chapter 6.

Independent variables: Household life-cycle indicators

Household life-cycle variables can be classified into four types: (1) variables that determine adult labor availability (e.g., all adults, adults males), (2) those that determine the number of age dependents (number of dependents, dependency ratio), (3) those that measure the influence of gender roles (number of adult women) and (4) those that are indicative of time spent on the lot (years on the lot; age of household head). These variables were easily obtained from both the 1992 and 2002 surveys and together serve as a robust indication of the relative position of a household along its life cycle. These variables are used to compare the power of household life-cycle indicators against other types of variables in explaining, (1) property fragmentation and consolidation processes, (2) property ownership changes, (3) land use and land cover change processes.

Variables that determine labor availability refer to the amount of household labor available such as *adult household labor* or *number of adult household men*. For this study I assume the working age is between 16 and 65 years of age. Household life-cycle models

usually expect an inverse U relationship for the availability of adult household labor, suggesting it is low at the beginning and at the end of the household lifecycle and peaks in the middle. This assumes a household arrives at a young age when only two adult workers exist and that most of the young adults that help in the middle stages of the life cycle will eventually marry and migrate to look for land of their own (empty nesters scenario). An alternative scenario finds the young adults staying and using part of the original property as their own or taking over the original household land use classes (generational shift scenario).

Equally important to consider in household life-cycle models are the variables that determine the number of dependents in the household. An important indicator for considering the impact of dependents in household life-cycle studies is the dependency ratio, or the ratio of adult laborers to dependents. According to the household life-cycle models, the number of dependents and the dependency ratio have a U form, being high on the initial and latter phases of the life-cycle and reaching its low-point in the middle phases. For this study, dependents are classified as all household-level members younger than 16 years of age and older than 65 years of age.

A third type of variable refers to the impact of gender related impacts. Gender roles can have an impact over land use strategies but these are not usually specified in household life-cycle models. Also, only the data set of 2002 discriminates the demographic structure of the household. As in the case of the number of working-age adults, we would expect an inverted U distribution over time, with lower values in the initial and latter stages of the life-cycle and a peak in the middle. However, we expect the impact of women over land use will be different than in the case of males, favoring the security of the household in the case of land use classes (e.g. subsistence crops) and its stability, in the case of property size and ownership patterns.

The fourth variable type indicates the amount of time the household has spent on the lot or on the region, as well as its life-time experience. Three variables are used throughout the study; (1) the *duration of residence on the lot* or *years on lot*, (2) the *number of years in Rondônia*, and (3) the *age of the household head(s)*. *Duration of residence on the lot* indicates the labor time, in years, that the household has invested in making the lot productive. For households that own more than one lot I consider the

number of years in residence on the longest-owned lot. *Years in Rondônia* is also indicative of accumulated experience but specifies the region instead of the lot which can sometimes be different. Theoretically, *years on the lot* is indicative of accumulated wealth and productive area in the lot, while *years in Rondônia* is associated with accumulated knowledge of farming practices in the region (Moran 1989; Perz 2002). More *years in Rondônia* should be indicative of accumulated experience in the region and therefore better land use practices (Moran 1989).

Finally, the *age of household head(s)* is an indicator of the time the household has been active economically, which estimates knowledge accumulation but not necessarily linked to the region. It is also probably the most closely associated with the position of the household along its life-cycle (Barbieri et al 2005).

Household life-cycle indicators are tested against other theoretically important variables. Using the “livelihood strategies” approach (Ellis 2000; Sherbinin et al. 2007) these would include;

Natural capital: the natural resource stock, or local environmental endowment (including water availability, soil, forest resources, etc)

Social capital: social resources, such as interpersonal networks, membership in groups, relationship of trust, access to wider institutions

Human capital: including formal and informal education, local ecological knowledge, the ability to work and good health

Physical capital: including productive assets held by the household (land, tools, working animals) as well as regional or communal assets (roads, communication)

Financial capital: typically, the most recognized of assets, including cash savings, credit or regular remittances and pensions

The household life cycle can also have an impact over some of these other independent variables, which in turn affect property-level decision-making processes such as property turnover and land use change processes. These impacts will be reviewed in the corresponding chapter were it is tested.

Analytical definition of the “end of the life-cycle”

In order to test for the capacity of the household life-cycle theory to explain land use and social change I specify an analytical definition of the end of the life-cycle. As most of the households that arrived in the study areas reach the end of their life-cycle it was important to test if the noticeable changes at the property-level and in the land use strategies found in the field were due to the aging characteristics of the households and therefore linked to the end of the household life-cycle.

The model presented in chapter 2 (Figure 2.3) represents theoretically the relationships between the different factors that impact land use and social change as the household reaches the end of the household life cycle. Therefore, different scenarios are possible. I classify the end of the household life-cycle under two scenarios described in the literature review; (1) the empty nesters, and (2) the generational change. The “empty nesters” scenario follows the conventional life-cycle model (figure 2.1) and is characterized at the end of the life-cycle by the migration of the sons and daughters from the lot to look for land of their own. The demographic composition is characterized by an aging household head and an increase in the number of dependents in relation to adult labor (an increase in the dependency ratio). In a “generational change” scenario the household is also characterized by an old-age household head, however the ratio of dependents to adult-household workers does not increase as in the empty nesters scenario since most of the sons and daughters remain on the lot and either fragment the existing property or expand into neighboring land if the household has been able to grow economically. The dependency ratio stabilizes or increases slightly by the arrival of a new generation of children but does not peak to its initial levels as it does in the empty nesters scenario.

Therefore the end of the life cycle is specified by the life-cycle indicators as having; (1) an aging household head, for our definition older than 65 years of age, (2) a very old residence time in Rondônia, in our case, households that have arrived in Rondônia at least 25 years ago, and (3) a long residence-time spent on the lot, in this case, households that have spent at least 20 to 25 years on the longest-owned property in the region. The fourth indicator, the ratio of dependents to working-age adult household members will depend on how the household reaches the end of its life-cycle and will vary accordingly. If the

household meets the above requirement and reaches the end of the life-cycle with an high dependency ratio, in our case higher than 1.50, we would claim it's an empty nester, with the appropriate changes in property size, ownership and land cover changes (diminishing areas under production and increasing secondary growth). If the household reaches the end of the life-cycle and maintains a low dependency ratio, lower than 1.50, I would claim the household is following a generation shift in its management. I would therefore expect an increment in its areas under production (annual crops and perennial crops) and diminishing its areas in pasture, secondary growth and forest resources. The changes in property size, ownership and land use classes are further specified in the chapters that address each of these issues.

Summary and Conclusions

This dissertation seeks to test the household life-cycle theory in the present context of an emerging post-frontier scenario in the Amazonian state of Rondônia. Its broader objective is to understand the emerging social and environmental characteristics of the post-frontier landscape to better inform policy and decision makers of the factors that are shaping it. Most land use change models are based on the household life-cycle therefore I hypothesize that many of the emerging patterns and processes can be explained using household life-cycle indicators. I analyze these in light of three emerging trends important of land use change studies; (1) property fragmentation and consolidation processes, (2) property ownership changes, and (3) land use and land cover changes. I hope that these research results will provide information useful to researchers and policy makers in their efforts to curb deforestation levels and promote more sustainable land use practices.

CHAPTER 4

DEVELOPMENT AND UNDERDEVELOPMENT IN THE AMAZON: ECONOMIC POLICIES, THE STATE AND THE ENVIRONMENTAL HISTORY OF RONDÔNIA

Introduction

Brazil's Amazon region comprises 3.87 million square kilometers of territory covering more than 60% of the 7.86 million square kilometers of the Amazon River basin (IBGE 2001). Its relative inaccessibility, low population density, and historically closer economic ties with neighboring countries and international markets, made it the focus of numerous regional and development colonization programs since the 1850s (Mahar 1979; Browder 1988). The purpose of this chapter is to briefly summarize the history of the region and how it has shaped the present day social, political and economic context of the Amazonian post-frontier. It describes the conditions that led to the expansion of the agricultural frontier and the massive immigration of colonists into the Amazon region. Finally, a review of the different stages that fostered this colonization reveals the patterns of social and environmental change from frontier to post-frontier period. I further attempt to link these changes to the theoretical frameworks guiding these policies and the consequences for the region and for our understanding of the Amazonian frontier.

Amazonia: Brazil's western frontier

The story of the modern occupation of Rondônia starts in southeastern Brazil, in the rural homesteads of the sharecroppers living off the large coffee producing agricultural estates in Espírito Santo, Parana, Santa Catarina and Rio Grande do Sul. Sharecroppers had a symbiotic relationship with the coffee estates, whereby they served as available labor during the harvesting period and produced food consumption crops for their subsistence and domestic markets between harvests. In the 1960s – early 1970s, development programs led by the Brazilian government attempt to “modernize” the agricultural sector, promoting the conversion of coffee estates into mechanized soy bean farms and releasing millions of sharecroppers from their land and into migration waves

opening forested frontier regions, many in the margins of the Amazon forest. In an effort to accommodate the surplus labor force the state created government supported colonization projects (e.g. POLONOROESTE) further opening up the frontier into the Amazon region. The peasant forms of production which were liquidated from the southern states of Brazil suddenly reappear in the Amazon frontier, replicating many of the crops and agricultural practices in this new frontier region, despite that soils were not appropriate for many of these crops (e.g., coffee). This continues well into the 1990s when Brazil emerges as a superpower in the global cattle market, which has shifted the major land use class from agricultural practices towards pasture. Therefore pasture expansion is the result of the articulation of the agricultural sector in Rondônia to the emerging cattle economy, while some farmers have “expended” their soil nutrient stocks, others more prone to adapt have emerged as new born cattle ranchers. Pasture brings in a whole new dynamic to the landscape since it inhibits regrowth of natural vegetation even in idle productive spaces. The adaptation of small landholders to the emerging cattle markets has become the key to explain their survival in the market economy.

Before describing the different stages of the historical occupation of the Brazilian Amazon, it is important to consider the role positivism and the military had in shaping the popular imagery of Amazonia. It can be argued that the image of the future that prevails in a society directs the course of events that define that society. In the case of Brazil, Amazonia has played a significant role in shaping the imagery of Brazil’s future.

Positivism, through the writings of Charles Darwin, Herbert Spencer and Auguste Comte had an important impact on the newly developed Brazilian republic and its influence is embodied in the Brazilian constitution of 1891 (Diacon 2004). The third article of the constitution mandated the transfer of the Brazilian capital from the coast to the center-west region of Brazil. Comte’s writings that social progress could be attained through the application of scientific principles to all aspects of society were widely adopted by the Brazilian elites of the late 19th century (Diacon 2004). The modern vision of Brazil became one in which science and industry would lead it into a brighter future. Progress became associated with the positivistic notion of social order or social stability as necessary for development. The words *ordem e progresso* (order and progress) became the national motto and are still inscribed on the Brazilian flag to this day. One of the

institutions that most strongly adopted these positivistic ideals was the *Escola Superior de Guerra*, the Brazilian War College, where several of the leading military dictators and promoters of state-led colonization projects in Amazonia during the second half of the 20th century were trained.

Amazonia became part of this positivistic vision of progress. Since before independence, Brazilians have viewed an expanding west as a necessary step for the future development and integration of their country. Despite the fact that numerous indigenous peoples, rubber tappers and *caboclos* populated Amazonia, the region was perceived as a demographic vacuum which needed to be conquered and integrated into the rest of Brazil just as the American west had to be integrated into the United States. Brazilian leaders, especially in the military, saw this emptiness as a threat to national security. Neighboring countries, and even the United States, could take over this land, tempted by the wealth just lying there waiting to be discovered. Colonization by Brazilians was necessary to guarantee ownership in the region. However, colonization was also important because it was believed that the region's wealth could fuel the development of the country. This ideology of developing the country and preventing foreign invasions by exploiting the Amazon rainforest would be symbolically initiated by the transfer of the capital to Brasilia in the 1950s and would gain prominence throughout several military dictatorships that characterized Brazil from 1964 to 1984. Before moving on to the modern occupation of Amazonia, the following section briefly reviews the historical occupation of the Brazilian Amazon.

Historical occupation of the Brazilian Amazon (1800s–1950s)

Brazil's Amazon region has been historically characterized by the various cycles of natural resource extraction such as timber, rubber, animal hides and gold (Mahar 1979). Human migration within the region was linked to the economic boom and bust cycles created by the extraction of these different natural resources (Bunker 1985). The state's role in the colonization of the region was limited to supplying labor to industries extracting forest products and other natural resources. As a result, the area remained sparsely populated, with few permanent settlements due to disperse resources and the fluctuations in the markets for these products.

The most significant of the boom and bust cycles was the rubber boom, which lasted from roughly from 1860 to 1912, when rubber plantations in South East Asia replaced the monopoly that the Amazon region had enjoyed for an extremely prosperous but short period. A smaller rubber boom appeared during the Second World War due to increasing demand from Allied countries for rubber. Although it ignited a new wave of migration into the Amazon, it was very short-lived. Other boom and bust cycles followed with timber, gold and animal hides as important commodities, interspersed by periods of economic stagnation, characterized by slow mobility and more diversified economic strategies. The reliance on economic boom and bust cycles created a very mobile, extractive-based population³⁹, which mixed with the indigenous peoples to create today's riverine populations locally called *caboclos* in Portuguese and *ribereños* in Spanish. Bakx (1987) described this era as a mixture of merchant capitalism and peasant subsistence agriculture. Foweraker (1981) terms it the "pre-capitalist stage" of commodity production, with periods of intensive resource extraction and migration that fueled little if any real development growth within the region.

The failure of this era to create long-term prosperity and the relative isolation that Amazonia maintained during the rubber boom period from the rest of the nation's economy predisposed it to be quickly forgotten. Although the rubber boom created incredibly long distance migration movements into the region, the massive migrations of the people that make up most of today's rural population in Rondônia were still to come. The failure of rubber and other natural extractive products to develop the region set the stage for drastic changes in government policies on how to develop the region. Rubber tappers, riverine populations and indigenous people were to become invisible in the new development discourses (Little 2001; Schmink 2003), reinforcing the empty forest myth and promising land up for grabs in what would become one of the greatest development planning schemes of the 20th century.

Modern frontier expansion in the Brazilian Amazon (1950–1990)

³⁹ This mobility refers to the longer span period, considering labor was so scarce it would migrate depending on the which extractive commodities they were engaged in; during climax boom cycles, especially the rubber period, many of these families were virtually slaves and therefore not very mobile.

Recent frontier expansion and deforestation in the Amazon is directly linked to Brazil's post-World War II strategies for modernization and economic growth and to the Brazilian authoritarian regime's (1965–1985) attempts to ensure national security within its national borders. While efforts to integrate the region can be traced from the colonial era through the rubber boom (1870–1920), the deforestation and migration patterns since 1970 arise from a new series of state-sponsored programs to colonize and develop the region. Unlike the previous waves of migrants who came to work in rubber and other natural extractive commodities, the new wave of settlers was lured by the promise of free land and massive infrastructure projects to link the region to the rest of the nation. This new phase of frontier expansion had dramatic consequences on the magnitude and long-term effect of the advance of the agricultural frontier into Amazonia.

The Amazon region was an important component of Brazil's modernist project to integrate into world economy. The advent of the pioneer frontier in Amazonia presented in the literature can be attributed to three historical and interrelated factors: (1) the mechanization of agriculture that displaced millions of sharecroppers in southeastern Brazil; (2) geopolitical military strategies to protect the nation's borders, and (3) the economic accumulation within the Brazilian nation and subsequent increase in demand from national markets. The action of the state was central in defining and promoting these changes.

In order to understand the underlying forces driving frontier expansion, it is important to recognize the epistemic frameworks that guided state intervention in promoting these changes. Following World War II, development economics appeared as a necessary and indispensable tool for guiding policies to modernize third world nations and societies. Brazil engaged in the modernity project by encouraging import-substitution policies to promote economic growth. These policies were guided by the economic models of Harrod-Domar⁴⁰, Arthur Lewis⁴¹ and Rostow⁴², which legitimized the role of

⁴⁰ The Harrod-Domar model calculates an economic growth rate ($\Delta Y/Y$) as a function of savings and a capital-output ratio. The capital output ratio is in turn the impact of each additional unit of capital on production. Underlying this equation is the assumption that capital, such as investments in plant and equipment, is the main determinant of growth and savings, by individual people and corporations, make investments possible. Economists applied (and still apply) capital-output ratios to poor countries to determine the required investment rate for a target growth rate. The difference between the investment required and the country's own savings is called the financing gap. Foreign aid is estimated to fill in the financing gap.

state intervention in the market economy to support economic growth, envisioning a predictive linear pathway to modernization. Furthermore, the fast economic growth Europe experienced after World War II supported the hypothesis that to stimulate development the government needed to inject huge amounts of capital into the economy and create the infrastructure that would snowball development. This was immediately applied to the developing world by transferring huge amounts of capital in the form of loans for large infrastructure development projects and foreign aid. However, development planners overlooked the fact that the real bottleneck was the third world's lack of human capital and experience in administering and managing these kinds of funds. The consequences of the debts incurred after World War II in the third world are still felt today.

Import-substitution policies to modernize the industrial sector were aimed at relieving surplus labor from rural areas by moving it to urban centers⁴³. The surplus labor was needed to set up the industries that would free developing nations from importing goods to create the demand that would fuel the modernization of agriculture and industry. In the eyes of Brazilian development planners, the sharecropping systems prevalent in rural Brazil had to be transformed into highly mechanized agricultural systems. The labor that would be freed would fuel industrial growth closer to urban centers and expand the agricultural frontier into new regions—specifically the Amazon. The expansion of the

⁴¹ Arthur Lewis's dual sector structural change model attempts to account for wide structural changes in the economy deemed necessary to move from a traditional subsistence agricultural economy to a modern industrial economy. The model argues that in developing countries, a surplus of labor in the agricultural sector that is producing at subsistence levels can be moved to a more productive industrial sector. When the marginal costs of moving labor from agriculture to industry becomes equal, the economy will be modernized and more economically efficient.

⁴² Rostow created a five stage linear approach to development. In this theory, it is suggested that all nations have to pass through a series of stages in order to achieve sustainable growth, moving from an agricultural subsistence economy to a modern industrial one. Rostow presented historical evidence of how most developed nations went through these stages and that it was only a matter of time for all societies to achieve this linear growth pattern. The critical stage for economic development is the takeoff stage, in which major breakthroughs in technology and capital investment allow the nation to take off on path to sustainable economic growth. Rostow argued that the only constraint preventing developing countries from reaching the takeoff stage was their ability to invest in technology and developed countries could help them achieve this through foreign assistance in structural development. Rostow later became one of the chief advisers of the Kennedy government, where his ideas helped push through the foreign aid programs implemented at the time.

⁴³ Links between development economics and the policies to fuel economic growth supported by developing countries are extensively and critically reviewed in Long (1977), Escobar (1995) and Peet (1999).

agricultural frontier into the Amazon was also a political and military strategy: it allowed the government to relieve political pressure for agrarian reform, it served as a safety valve for thousands of sharecroppers displaced by the mechanization of agriculture (specifically the conversion of coffee estates to soy beans) and it was viewed by military strategists as a necessary step to secure national borders against neighboring countries. However, in practice the prevailing economic interest of national and foreign enterprises would make them the foremost beneficiaries of state investments in promoting the integration of the Amazon frontier.

Kubitschek and Brazilian manifest destiny

It is during the presidency of Juscelino Kubitschek (1956-1961) that the positivistic vision of progress and the nationalistic need to expand westward converged. He boastfully announced Brazil would advance fifty years in five in order to catch up with the developed countries (Barbosa 2000). Kubitschek's rhetoric makes reference to the Turnerian themes that justified policies fostering the imposition of new settlements of remote regions occupied at the time by indigenous peoples. It was during his presidency that the transfer of the Brazilian capital to present-day Brasilia, as mandated by the constitution of 1891, finally became a reality. In Kubitschek's vision the new capital would become the magnet that would draw together the forces that would expand development and social order to the interior:

The population nucleus created in that faraway region would spread like an oil spill, making the whole interior open its eyes to a glorious future for the country. Thus, Brazilians would be able to take possession of their vast territory. And the change of the capital would be the vehicle, the instrumental factor that would make this new cycle of conquest [*ciclo da bandeira*] possible (Kubitschek 1975 in Barbosa 2000: 33)⁴⁴.

Brasilia was to become the center from which the rest of the Brazilian interior, especially Amazonia, was to become integrated through a network of roads that would join "the gauchos of the pampas to the rubber tappers of the Amazon" (Kubitschek 1975: 8-9 In

⁴⁴ *Ciclo da bandeira* makes reference to the *bandeirantes*, flag-bearers that carried out expeditions into the Brazilian interior in search of slaves and resources, becoming part of local folklore as heroes since they expanded the size of the Brazilian nation by claiming the areas they explored.

Barbosa 2000: 33). In another example of Turnerian themes in the positivistic vision of Kubitschek he recalls the importance of the roads by drawing parallels between Brazil and the United States a century before.

In 1850 the United States laid open immense western pastures, aiming to link the Atlantic to the Pacific. When I initiated the Brasilia-Acre highway, I was realizing an identical adventure. And I was doing it with only a one-century delay. The objective of the road was the immediate integration of the southwest region of Amazonia (Kubitschek 1975: 314 in Barbosa 2000: 34).

It was the Belem-Brasilia and the Brasilia-Acre highways that Kubitschek initiated that would prepare the way for the massive invasion of migrant workers into the Amazon rain forest in the latter part of the twentieth century.

The establishment of Brasilia in the center-west of the Brazilian interior marks the beginning of the state-sponsored development of the Amazon region. However, it was after the military took over in 1964 that the influence of the state over the settlement of Amazonia intensified. Rapid economic growth and development of the Amazon region became political priorities of the military leaders that followed. However, to the ideology of progress as expounded in the positivistic ideals and emerging development economics principles of the time, the military added the need to populate the vast Amazon region before neighboring nations decided to do so.

Following Browder and Godfrey (1997) and Toni (1999) the modern occupation of Amazonia can be separated into four phases; the first from 1966 to 1970 is characterized by *Operation Amazonia* and the first years of the Superintendency for the Development of Amazonia(SUDAM); the second phase, from 1970 to 1974, is characterized by the government's interest in using the region as a "safety valve" and experiments in promoting populist fronts; the third phase, from 1975 to 1979, is characterized by the consolidation of Amazonian entrepreneurs to retain most of the large tracts of land in the new frontier fronts and by the POLAMAZONIA program; finally, the fourth phase, from 1980 to 1996, is characterized by a resurgence of the subordinate classes to organize themselves and get an active voice in policy making, promoting the populist shift in regional planning taking hold in Rondônia through the World Bank supported POLONOROESTE and PLANAFLORO projects.

These historical phases could also be classified according to the type of frontier establishment they fostered; the first and third phases have endorsed a corporatist type of frontier, promoting the establishment of corporate fiscal incentives and encouraging entrepreneurial investments over the interests of small land holders. The second and fourth phase could be described as favoring the establishment of a populist frontier, promoting rural credit and land settlement colonization programs for small farmers, at least on paper. The present landscape of property regimes and spatial distribution of frontier types can be linked to the establishment of the site and the historical context in which it was established. As shown by Browder and Godfrey (1997), contemporary Amazonia is much influenced by the different dynamics in populist and corporatist expansion fronts.

The military takes over: Operation Amazonia and SUDAM (1966–1970)

In 1965, the first military president after the coup—General Castelo Branco—declared he would establish a new model of development in the Amazon. He created a five-member committee to define development policies for the region and to draft all the legislation required to implement it. The result was Operation Amazonia, whose main objectives were to establish development poles and self-sustaining population centers; stimulate in-migration; create incentives for private capital; develop infrastructure and promote research on the natural resources of the region (Toni 1999).

Operation Amazonia intensified existing industrialization policies in the Amazon and reasserted national economic integration as the major goal of development policies in the region (Mahar 1979; Browder and Godfrey 1997). It is considered the first large-scale region-wide coordinated effort to integrate the Amazon and to encourage settler migration as part of a development program. The program called for “growth poles” to encourage migration and infrastructural development (Katzman 1977). It also attempted to address investment imbalances between industry and agriculture, a consequence of previous import-substitution programs (Bakx 1987).

In order to coordinate federal policies and development in the Amazon region the military created the Superintendency for the Development of Amazonia (SUDAM). The

new regional agency would be controlled directly from Brasilia, supposedly to counteract previous corruption and control of local interests. SUDAM was charged with formulating five-year development plans to attract private investments and promote agricultural expansion and modernization (Bakx 1987; Browder 1988). The first plan called for resource concentration in areas of existing and potential populations, the adoption of a migration policy and incentives for the exploitation of the region's natural resources (Browder 1988). SUDAM implemented these policies through two approaches: (1) increasing the infrastructural area, primarily the transport sector, and (2) giving tax credits and subsidies to corporations investing in approved projects within the region (Browder 1988)⁴⁵. Parallel to the implementation of SUDAM, a new regional development state bank, the Bank of Amazonia (BASA), was launched in order to channel funds to the region. The combination of these state agencies, SUDAM and BASA, promoted the establishment of large-scale agricultural enterprises, particularly cattle ranching.

Large-scale ranching resulting from the policies promoted by Operation Amazonia and SUDAM led to land consolidation by large landholders, as land within the region gained in speculative value (Foweraker 1981). The structural change was not only the result of recent policies but also the replication of the predominant latifundio-minifundio system that has traditionally dominated Latin America's rural regions (De Janvry 1981). For example, the area under production in Para increased four times during 1960 and 1972 but the total number of rural properties decreased from 83,000 to 40,000 (Foweraker 1981). Land concentration on the frontier induced the reproduction of Brazil's unequal system of land tenure and labor relations that predominates in other Brazilian regions into the Amazon.

Large scale agricultural production supported by Operation Amazonia and the policies implemented by SUDAM were accompanied by increased repression of the rural poor (Hecht 1985). Land consolidation processes forced subsistence farmers to give up part or all of their meager land holdings and seek employment elsewhere. Part of the

⁴⁵ Among the economic incentives, the one that caused the most controversy was Law 5.1744, passed in October of 1966. This law allowed a percentage (initially 50%) of a corporation's tax liability to be invested in projects in Amazonia. This allowed tax owed to become venture capital. Therefore, investors obtained property rights for land that they deforested just to get tax benefits.

problem was that the fiscal incentives provided by the state through Operation Amazonia and the SUDAM agency promoted cattle ranching and other large-scale enterprises instead of looking out for the welfare of the migrant poor. For example, only 1.4 percent of SUDAMs incentives budget were allocated to small farmers (Millikan [1988:32] in Browder and Godfrey 1997). Furthermore, subsidies ended up in capital intensive rather than labor intensive production; as few workers as possible were hired. The result, once the land was taken over by large economic interests, was further immigration into new forest frontiers.

Shifting the balance toward populist frontiers: PIN, PROTERRA and INCRA (1971–1974)

The military did not prioritize the colonization and development of the Amazon region by smallholders until after 1970, when rural workers in the Northeast of the country reached unprecedented levels of poverty exacerbated by droughts at the end of the 1960s. At the same time, social tensions throughout the Amazon region, especially the escalating violence due to land distribution problems within the Belem-Brasilia highway area of influence, led to major shifts in governmental approaches to colonizing the region. By 1971, the flaws of the *Operation Amazonia* era led to the creation of the Land Redistribution Program-PROTERRA in search of better approaches to the problems of land distribution and inefficient utilization of rural land. Another governmental strategy to deal with the land distribution problem was the creation of the National Institute for Colonization and Agrarian Reform (INCRA). INCRA's role would be agrarian reform, to resettle the landless in opening frontier regions. INCRA organized its land redistribution scheme under the heading of the National Integration Program (PIN). The program combined large infrastructural development with colonization projects. PIN's goals included the construction of the Transamazon highway that would link Brazil's poorest region, the northeastern states of Brazil with the northern Amazon region (Becker et al. 1990; Mahar 1979). The project actively sponsored the resettlement of "men without land" on the Amazon's "land without men".

These projects marked a shift in policy focus from purely economic development considerations to a more social perspective with the explicit goal of alleviating rural poverty through land redistribution programs (Moran 1981; Browder and Godfrey 1997). Despite INCRA's attempts to structure colonization projects, the expectations for land, especially in areas suffering attempts to modernize agriculture, led to massive spontaneous migration into the Amazon region that quickly overwhelmed the agency's capacity to settle migrant households (Foweraker 1981; Bakx 1987). Spontaneous migration exacerbated the land conflict problems that INCRA was designed to address. The repetition of this pattern at each of the project sites along the Transamazon highway indicated that the government had underestimated settler response and its own ability to plan settlement projections. Spontaneous migration, in turn, was fueled by modernization schemes in other Brazilian regions, especially its efforts to transform the agricultural base of the southeastern Brazilian states from labor intensive coffee plantations to mechanized soybean production (Bakx 1988; Browder and Godfrey 1997). But, while government officials viewed the Amazonian territory as a "safety valve" to redistribute displaced agricultural workers, other business interests had their own colonization priorities in the region. The Association of Amazonian Entrepreneurs (AEA) is a large but politically influential organization of absentee owners of ranching businesses in the Amazon (Pompermayer 1984). Their goal is to use political leverage to shift regional development policies to favor large-scale enterprise development in the region through corporate and fiscal incentives (Hecht 1985). The overwhelming problems of land redistribution in the region coupled with the political leverage of pro-corporate groups such as the AEA eventually led the government to reassess its goals for the colonization of the Amazon (Hecht 1985). By 1974, the populist front as a politically supported government effort had receded in favor, again, of SUDAM-like large corporate agrobusinesses as the development model to implement in the region.

POLAMAZONIA (1975–1979)

In response to pressure from large scale business interests such as those represented by the Association of Amazonian Entrepreneurs (AEA), the state created the

Program of Agricultural, Livestock and Mineral Poles in Amazonia⁴⁶ (POLAMAZONIA) in 1974. The AEA lobbied and convinced the Ministers of the Interior, of Planning and of Agriculture that an occupation based on private colonization and large scale ranching was the most appropriate model to promote development in the region. This was a major shift from the established model that favored smallholder colonization projects. These groups, led by the AEA, blamed peasant smallholders for environmental degradation processes and underdevelopment of the region, arguing that they lacked the managerial and technical skills to succeed in agriculture (Wood and Schmink 1979).

The military and their new allies gave an unexpected twist to the agrarian problem. According to their newfound discourse, it was the existence of *minifundios* (small farm properties), rather than the *latifundios*, that caused the backwardness of the rural sector. Conversion of *minifundios* into larger properties that could afford modernization was, according to this modern interpretation, necessary to develop the agricultural sector in the backwoods of Amazonia (Sorj. 1980).

The shift also meant the political victory of SUDAM over INCRA. The battle had been one of power and resources between the two bureaucratic institutions to implement their political agenda. As soon as POLAMAZONIA replaced PIN, most of the budget for developing the region passed from INCRA to SUDAM. INCRA adapted by abandoning its small farmer settlement scheme (Toni 1999). The new licenses limited private colonization projects to 100,000 hectares. By 1976 private investors could acquire up to 500,000 hectares for private colonization schemes. On the other hand, large areas that had originally been assigned to small farmers during the previous phase were reverted back to large land owners. Once again corporate cattle ranching became the regional agencies' preferred developer.

Still, during this period, spontaneous migration continued to increase. While INCRA no longer did much to attract migrants it could not control the increasing immigration that continued to pour into the region. New roads and the apparent availability of land continued to attract poor rural workers from all over the country. In 1979 the Brazilian government proposed the Northwest Brazil Integrated Development Program (POLONOROESTE) in an attempt to control the rapidly increasing numbers of

⁴⁶ Programa de Polos Agropecuarios e Agrominerais da Amazonia

migrants that were arriving in the newly opened state of Rondônia. This marks the beginning of state efforts to promote a new populist frontier based on small-scale landholder farmers.

The World Bank and the promotion of a new populist frontier in Rondônia: POLONOROESTE and PLANAFLORO (1980–1996)

In 1979, the Brazilian government initiated negotiations with the World Bank regarding the possibility of financing the reconstruction and paving of the São Paulo - Porto Velho (BR 364) highway. Several members of the Bank's staff expressed concerns over the advisability of funding a highway project through the heart of Rondônia, which until then had been a backwater state of rubber tappers and indigenous people. The experience of the Belem-Brasilia highway suggested it would stimulate further migration into pristine forests and indigenous territories, generating conflicts in regions until then relatively isolated from the rest of the nation. However, since it was believed that, with or without the Bank, the Brazilian government would proceed with its highway development plans, advocates of the program within the World Bank argued that by financing an overall development package, the Bank would be using its leverage to promote basic human and ecological concerns in the Brazilian Northwest region (Mahar 1983).

In December 1980, the World Bank announced its decision to finance the Cuiaba-Porto Velho highway as part of a larger development package aimed at promoting "orderly" development of the region. The package included the protection of critical physical environments and local indigenous communities. The total investment was 1.1 billion dollars for the period 1981–1985 and in May 1981, the federal government officially created the Northwest Brazilian Integrated Development Program (POLONOROESTE). Four major objectives were identified within the program: (1) the construction and paving of BR 364, 1450 km from Cuiaba (Mato Grosso) to Porto Velho (Rondônia), (2) the consolidation of older settlement projects in Rondônia and Mato Grosso, (3) the improvement of the regional land tenure situation through titling and establishment of new projects in unoccupied areas, and (4) improved capacity to insure

environmental preservation and protection of indigenous peoples (Pedlowski 1997: 69). However, only 2.1% and 1.0% of overall program funds were set aside for indigenous and environmental components, respectively.

The differences between planning and reality became evident by the mid-eighties when, despite the initial optimism of bank officials, settlement pressures had become anything but “orderly”. Indiscriminate land occupation and tropical forest clearing had resulted in the deforestation of some 4.2 million hectares by 1988. While total deforested area had gone from 0.5 % in 1975 to 3% in 1980, by 1988, 17.1% of the state’s total surface had been deforested (IBGE 2002). The arrival of new migrants during the first half of the eighties by far exceeded any of the original projections estimated by the planners of the POLONOROESTE project. From 1980 to 1986, the annual number of immigrants registered at border checkpoints increased threefold from 49,205 to 165,899 (Millikan [1988] in Pedlowski 1997). Apparently, POLONOROESTE planners had only planned for the resettlement of 15,000 families during the 1980’s.

Feeney (1998) argues that the underlying causes of the problems of POLONOROESTE, that were also going to be present in its successor PLANAFLORO, were the local economic elites, who exercised control over project funds and official agencies. Brent Millikan, cited in Feeney’s study, indicates that government agencies funded through the program served as the “launching pad” for political careers (Feeney 1998). For example, the former local head of INCRA was later elected mayor of Ouro Preto, the first major settlement project under the POLONOROESTE project; other agency officials would later become state senators (Feeney 1998).

Local interests not only used their power to establish alliances with politicians and agency staff, but would use it to reshape the land use zoning, conservation units, and settlement areas originally designated by POLONOROESTE planners, to meet their own economic interests (Feeney 1998). One of the major constraints of the program from the beginning was the limited availability of fertile soils to meet the growing demand for land in Rondônia. Not only had planners overestimated the capacity of existing state institutions to handle the increasing flow of landless migrant farmers flowing into Rondônia, but the “New Settlement Projects” were eventually established, not according

to ecological criteria as specified, but by the economic and political interests of local elites (Feeney 1998).

The limited amount of appropriate fertile land in Rondônia together with bureaucratic difficulties associated with the size of the program, resulted in the total number of land titles distributed through the program to fall far short of the estimated 15,000 anticipated in the original plan. This not only represented less than one-third of the families considered in the original plan, but due to the much higher number of migrants than expected, it also meant that by the mid-eighties only 12% of the migrants settled in Rondônia had received title to their land (Becker [1987] in Pedlowski 1997).

Another common practice of local elites and INCRA officials during the life of the POLONOROESTE program was to encourage migrants to occupy areas with low agricultural potential, or even of protected areas, with the promise that their claims would be recognized later (Feeney 1998). This ignored the technical aspects used by planners to designate colonization areas but allowed local elites to secure the most fertile lands for themselves and their allies and still allocate enough land to smallholder colonists to maintain their political support.

Although the bank had originally contended that the program would fund and assure the delimitation, creation and protection of indigenous territories and fragile landscapes, there was little political commitment on the part of the Rondônia state government and Federal agencies in charge of implementing the project. For example, although the World Bank refused to finance small farmer settlements in the Guapore Valley, the government of Rondônia was able to secure federal funds for road building and colonization (Millikan [1988] in Pedlowski 1996). Highway construction and settlement plans in the Guapore Valley had not been in the original plan since it would have constituted a major threat to the livelihood and survival of the Uru-Eu-Wau-Wau ethnic group who had until recently remained uncontacted.

The lack of political commitment of POLONOROESTE project personnel to demarcate indigenous areas and protect conservation units in the region resulted in increasing pressure from international NGOs and members of the U.S. Congress on the World Bank. Finally, in May 1985, the World Bank, under pressure from congress, temporarily halted disbursement of funds until the Brazilian government took steps to

demarcate reserves and indigenous areas and committed politically to their protection. This was the first time in the history of the World Bank that it suspended funds on social and ecological grounds⁴⁷. The constant scrutiny of international NGOs in the campaign to denounce the irregularities of POLONOROESTE, accompanied by media coverage of the deforestation and invasion of indigenous territories linked to the project, took its toll on the World Bank's image. The negative publicity brought by POLONOROESTE was central to the design of its successor, PLANAFLORO—the Rondônia Natural Resource Management Project.

PLANAFLORO represented the World Bank's attempt to commit itself to the environmental aspects of economic development. The program was divided into four major components: (1) environmental conservation, management and protection, (2) agroforestry development, (3) socioeconomic infrastructure and services, and (4) program administration. It shifted the main focus from infrastructure and resettlement to attempts at natural resource management projects with the participation of civil society groups. Still, the overall environmental and social consequences of the program were hard to control and monitor from the start. Many of the problems present in POLONOROESTE persisted in PLANAFLORO despite its good intentions. As the PLANAFLORO program was ending a new phase was opening up in Amazonia that was to impact all frontier types; a new era of rising national and global markets was going to shape the post frontier and emerging frontier regions alike, including the small landholder strategies.

Amazonia enters the age of globalization (1996 – present time)

Today, Amazonia is in a new phase of occupation, in which the role of fiscal incentives have a reduced impact, while market-based incentives, such as profits from

⁴⁷ After 1987, the World Bank responded to outside pressure, of which POLONOROESTE was one of its most visible critical projects, by internalizing these concerns through: 1) changes in organizational structure and staffing which resulted in the establishment of four regional offices with environmental units and a central Environmental Department, 2) changes in timing program cycles to incorporate concern for environmental issues at different stages of the programs, 3) incorporation of nongovernmental organizations in the development process (Brown, [1992] in Pedlowski, 1998). In 1993 the World Bank established an independent Inspection Panel, allowing citizens to demand accountability without involving their governments. However, criticism persists, claiming that, although these changes have increased the legitimacy of the Bank, it has not yielded significant changes in the democratization of the Bank's development practice (Rich [1994] in Pedlowski 1998).

extractive and cattle ranching activities guide the transformation and expansion of the frontier (Margulis 2004). These processes are being reinforced by expected governmental investments in infrastructure. The *Avanca Brazil* program, today renamed *Plano Brasil para Todos* are aimed to integrate the Amazonian region to the national and international economies. While Amazonia was always considered in the periphery of the national economies of South American countries, it now finds itself in the middle of the proposed continent-wide development projects to integrate them. Proposed roads, railroads and waterways will link the south-central part of South America (southern Brazil, Argentina, Uruguay and Paraguay) with the Pacific and the Caribbean Oceans through and into the heart of the Amazon region. What differentiates this new phase of occupation from previous ones is that it is the first time in our history that the economic, demographic and political conditions for the definitive occupation of Amazonia are in place.

As the Brazilian Amazon region has grown increasingly articulated to regional and international markets deforestation levels have become closely correlated to economic growth indicators such as GNP (Fearnside and Laurence 2003). This relationship starts in the late eighties with the end of agricultural subsidies, and the imposed structural adjustment programs implemented between 1987 and 1991. During this interval deforestation levels reduced significantly from 15 to 5 million square kilometers per year (Lele et al. 2000). With the recovery of the national economy deforestation levels rose again at the start of the 1990s only to fall again during the second half of the 1990s correlating with similar trends in the Brazilian economy. It could be concluded that deforestation is responding to the availability of capital in the national economy and therefore, as more capital is available more investments are done in Amazonia that require deforestation. This would limit deforestation to large landholders and other forms of capitalist interests. However, starting in this decade increasing national GNP is not the sole factor that is contributing to the growth of deforestation levels since similar increasing deforestation levels have been associated with small landholders. As Brazil enters this century as the new economic superpower in South America, it has unleashed a series of regional and global forces into the Amazon that are radically reconfiguring its landscape.

Since the year 2000, deforestation seems to be linked more and more with the rising global demand for beef and soybeans. Brazil has become the new beef producing powerhouse due to the devaluation of the Brazilian currency on one hand and the control of animal diseases such as foot and mouth disease on the other. At the same time, private firms such as that led by the Maggi group have invested heavily in infrastructure to get agricultural products from Amazonia to the global markets that are increasingly demanding crops such as soybeans. Therefore soybean farmers and cattle ranches are expanding their production into frontier areas, taking advantages of cheap land and transportation improvement. Although in the end of the production chain, small landholders are increasingly responding to both, the pressure for land for increasing the production area for cattle in old frontier regions and the rising demand for cattle raising pastures where land is still abundant. We are only starting to understand the impact that these processes are having over the small landholder systems of production but infer that it is increasing in importance over the years.

Consequences of state-promoted development processes in the Brazilian Amazon

The recent occupation of the northwestern Brazilian state of Rondônia has been underway for nearly 40 years. Policy action, conditioned by economic forces and biophysical factors, has had direct and indirect consequences for economic growth, environmental sustainability and demographic change. Although macroeconomic indicators look favorable, it is important to look at the environmental history of the region to determine the environmental costs of this economic growth, as well as at the household level to identify its social implications.

From 1965 to 1995 more than 500,000 families settled in new colonization projects or spontaneously invaded forest areas along major highways that were opened throughout the Amazon. In Rondônia the population grew from 36,000 in 1950 to more than 1.2 million in 1996. As a consequence, population density levels in Rondônia rose from 0.5 persons per square kilometer to 5.2 persons per square kilometer in 1996 (IBGE 2000). Starting in 1970, the western Brazilian Amazon also experienced rapid urbanization. It is estimated that by 1996 more than 60% of the region's populations

settled in the growing cities and towns that appeared in the region (Browder and Godfrey 1997).

The environmental consequences of the policies pursued in the region have also been substantial and, most of the time, negative. In the past 30 years, forest cover has been considerably reduced, with consequent increases in carbon and other greenhouse emissions, loss of biodiversity, productive soil loss, nutrient leaching and land degradation processes. In Rondônia, forest conversion has been particularly dramatic. Accelerated settlement and agricultural programs through POLONOROESTE and PLANAFLORO have resulted in the deforestation of almost 28% of the state's original forest cover by 2002 and this does not include areas degraded due to illegal logging activities and fires. It is still questionable whether the mechanisms set in place by the World Bank to mitigate the negative impacts of these development projects worked to scale down deforestation and social conflicts (Feeney 1998; Browder 2002).

In the case of Rondônia, which was mostly colonized by small landholder farmers migrating from the southeastern Brazilian states (Parana, Santa Catarina, Espirito Santo, Rio Grande do Sul and São Paulo), most of the area was cleared through slash and burn agriculture. Among small landholders, clearing forests is usually followed by annual crops, which can grow on the nutrient uptake from the burned forest biomass for about 2 to 3 years before productivity levels diminish. Thereafter the area is cultivated with perennial crops, which can produce for another 6 to 8 years, or it can be burned again and turned into pasture for extensive cattle ranching. With time, the farmer's lot will decrease in forest area (usually 2 to 5 hectares per year depending on household labor and other factors that will be discussed in subsequent chapters) and increase the proportion of the cultivated area in pasture. Other land uses, such as perennial crops and agroforestry systems, can absorb household labor and contribute to household income considerably, but these areas are small compared to the relative extensive nature of pasture (Browder 1994; Vosti and Witcover 1996; Browder et al. 2004).

Dramatic deforestation levels in Rondônia are leading to extensive losses of soil productivity and water availability. The negligence of the planners and policy makers of development schemes in Rondônia led to thousands of farmers settling on lands that could not support agriculture of almost any kind (Feeney 1998). Consequently, soils

became degraded and unproductive after just a few years. With no financial capacity to keep soils in production, and with the continuous opening of new frontier fronts, farmers keep deforesting year after year, accelerating deforestation rates in the region. Moreover, many farmers are experiencing water scarcity levels as regional climates become drier year after year and livestock growth continues to dry up the existing water sources in the region. It is estimated that by 1997, 55 million hectares of forests in the Brazilian Amazon (14% of the total area) had already disappeared while another 25 million hectares are considered degraded forests due to logging and fires (INPE 2000). Additionally, it is estimated that in Rondônia 500,000 hectares of degraded pasture and 140,000 hectares of secondary fallows (INPE 2000) already exist.

While the policies implemented in the Amazon region have resulted in waves of migration and subsequent deforestation and social violence, some researchers, particularly economists, argue that substantial progress has been achieved in terms of economic growth during the last 30 years (Ozorio de Almeida and Campari 1995; Faminow 1998; Andersen et al. 2002; Margulis 2004). In Rondônia, where deforestation attained dramatic levels, substantial increases in economic indicators can be found. For example, in 1995, Rondônia had become the fifth largest coffee-producing state in Brazil and with 70% of its deforested area converted into pasture, the state reached 8 million head of cattle by 2002 (367% increase from 1990 levels; EMATER 2002). Per capita gross domestic product in Rondônia also rose, from \$2025 in 1970 to \$6500 in 1996, close to the national average for Brazil for that year (Faminow 1998).

Indicators of human wellbeing (e.g., education, health) also show significant progress according to some studies. For example, school matriculation rates in Rondônia more than doubled during the last 25 years, from 32% in 1970 to 71% in 1996 (Valentim and Vosti 2000). Over the same period, life expectancy rose from 53 years to over 67 years and illiteracy rates decreased from 30% to 14%. The UNDP human development index for Rondônia also rose from 0.47 in 1970 to 0.82 in 1996, attaining almost the national value of 0.83 for Brazil as a whole (Valentim and Vosti 2000).

State-sponsored development schemes in the region show contrasting impacts; on one hand, the negative social and environmental consequences and, on the other, the economic prosperity of the migrants. While the initial phases of frontier colonization are

characterized by environmental degradation and social unrest, the present post-frontier context stresses the economic prosperity of small landholder migrants, and the region, over time. Another important outcome of state-sponsored colonization programs has been the widely divergent patterns that appear in the populist and corporate types of frontiers. Although this study centers on colonization programs that were developed during the populist stage of frontier expansion, it is important to contextualize findings within the broader realm of other frontier types. Finally, the characteristics of the socioenvironmental history of frontier expansion in the Amazon do not resemble the original frontier thesis and the positive connotations associated with it, such as the formation of a local identity and institutions. Instead, it follows other Latin American versions of the frontier experience that stress the conflicting nature of the frontier and its negative associations (Weber and Rausch 1994).

Conclusions

The present chapter has reviewed the major historical stages that characterized frontier expansion in the Amazon region. It focused on the last stages in which the state of Rondônia is a major protagonist. Development schemes in Rondônia applied innovative ideas in development planning but it ended up as one of the regions in Amazonia with the most negative social and environmental impacts. Others argue that this is the expected cost of developing the region economically. It is still arguable whether economic growth based on unsustainable land use practices such as cattle grazing will persist over time or will be outweighed by negative environmental and social costs. Therefore it is essential to examine the evolution or life cycle of small landholders to determine the viability of this mode of production over time. Interpreting the causes and consequences of land use change as part of the history of Rondônia sets the stage for understanding the conditions that characterize the small landholder in the post-frontier region of today. Unlike the original plans for developing the region, numerous other factors played a more decisive and critical role in molding the present context. The roots of the present conditions of environment and land degradation are to be found outside the small landholder farm, in the structural conditions that allowed the deforestation process to go beyond the state's capacity to order and implement its populist settlement programs.

However, the household mediates how these conditions affect land use decisions at the farm level. Understanding the effect of patterns at the household level over land use (e.g., life cycle) can help determine how policy interventions can have a better impact on the household's capacity to adopt more sustainable land use options. However, this needs to be considered within the broader historical and biophysical context in which the household evolves. The present chapter serves as a background from which discussions of the processes of land use change at the household level can be discussed. The next three chapters examine specific impacts of household life cycle variables on land use change in the present context of the post-frontier scenario. As the frontier closes and the original settlers reach the end of their life cycle, it is important to review the links between land use change and household life cycle.

CHAPTER 5

DEMOGRAPHIC CHANGES, LAND OWNERSHIP PATTERNS AND PROPERTY SIZE DYNAMICS IN A POST-FRONTIER REGION (1992–2002)

Introduction

The household life-cycle theory has become one of the most important theoretical frameworks for understanding land use and land cover change in the Amazon region and is represented by a diverse literature (Henkel 1982; Thiele 1995; Marquette 1998; McCracken et al. 1999; Perz and Walker 2002; Walker et al. 2002). One version of this theory argues that frontiers move through a predictive set of stages corresponding to the life cycle of pioneer families. Therefore, the landscape evolves, in part, as a consequence of the land use decisions of the households that originally settled in the frontier. Decision making in households is, in turn, circumscribed by their position in the domestic life cycle. As a household moves through its life cycle, characteristics such as availability of family labor, experience in the region, and ratio of consumers to producers in the family change, constraining or enhancing the ability of farmers to effectuate changes in land use.

The frontier also changes as a result of its integration into the national economy. Over time, infrastructure such as roads, schools and markets develop, influencing the land use decision-making process of farmers and, consequently, the landscape. Therefore, although household life cycles affect land use decisions, these are embedded in the larger context of forces driving the frontier's fluctuating integration into the national and global political economies. Because of this feedback effect, the variations in status of frontier households over time are associated with the dynamics of both the farm and frontier. The focus on a dynamic understanding of frontier development based on the household life-cycle theory in a political economy framework has been a powerful conceptual model for Amazon frontier expansion research. However, as I argue in this dissertation, it still falls short of accounting for the complexity inherent in frontier dynamics. Current models, I

contend, neither address changes in ownership nor substantially explain property fragmentation and consolidation processes occurring in the latter stages of a household's life cycle, both of which can contribute significantly to the character of the post-frontier in contemporary Amazonia.

The objective of this chapter is to analyze changes in property ownership and property size among small landholders in a post-frontier Amazonian setting. It first explores descriptively how the Rondônia landscape has changed during the last ten years based on demographic and property level variables at the household lot level. It further tests the validity of the household life cycle for explaining these processes of land cover change. Observations in the field and preliminary analyses of data indicated widespread aggregation and fragmentation of the original properties surveyed in 1992 (Browder et al. 2005). Additionally, many properties have undergone ownership changes due to selling all or part of the property or to generational changes when the original owner passed the management of the property on to his descendents. The existence of farmer ownership changes as well as property aggregation and fragmentation processes, over time, may have important implications for the processes of land cover change (Ozorio de Almeida and Campari 1995; Browder et al. 2005) but are still poorly accounted for within the household life-cycle theory. In this chapter, I test the hypothesis that the household life cycle plays an important in determining the processes of (a) property ownership changes, and (b) property fragmentation and consolidation.

This chapter attempts to answer three interrelated questions:

- 1) What are the property size dynamics and ownership patterns of landholdings in the post-frontier as the original settlers reach the end of their life cycle?
- 2) Can the household life-cycle theory explain changes in the ownership of land?
- 3) Can the household life-cycle theory determine the subdivision and consolidation of properties?

The chapter is divided into seven sections. The following section reviews methods and definitions of variables. The third section presents a descriptive analysis of demographic changes through time, of the processes of property ownership and property consolidation and fragmentation changes. The fourth section classifies the households in the sample frame into groups based on changes in property ownership and size. I then use ANOVA and chi-square statistical tests for comparing theoretically important household life-cycle variables across these different farmer groups. The section also specifies testable hypotheses to determine if the position of the household in its life cycle explains changes in property ownership and property size. The fifth section is a regression model that measures the changes in overall landholding size using theoretically important household life-cycle variables as independent variables. The sixth and seventh sections correspond respectively to the discussion and the conclusions.

Methods

A majority of the households in the study sites were found to be approaching the final stages of their life cycle, which correspond to considerable property fragmentation and consolidation processes as well as high rates of property turnover. Such changes in property ownership patterns and size are yet to be incorporated in conventional theoretical frameworks of frontier studies. Keeping this shortcoming in mind, I formulated a model based on the household life-cycle theory which explains property turnover and property fragmentation and consolidation processes over time (Figure 2.3). The model was reviewed in chapter 2; in this chapter I will test it using the empirical data from the panel survey data set.

This section conceptualizes the variables that define (1) property ownership status, and (2) degree of property fragmentation and consolidation. These variables are then used to classify farmers based on these characteristics and determine if they in fact correspond to different types of farmers. The variables that will be defined in this section include: old and new owners, rural owners and absentee owners, lot fragmentation and lot expansion, property expansion and property reduction.

Property Ownership changes

Continuous and New Owners (farmer types): In order to measure changes in the status of property ownership, households are classified into old owners and new owners. A continuous owner is one who has continued to own the same lot throughout the entire study period (1992 to 2002). A new owner refers to a 2002 survey respondent who acquired a lot in the sample frame since 1992. New owners also include members of the same households who acquired property in the sample frame between 1992 and 2002 through inheritance (the generational shift) .

Lot and property size changes

a. Lot Fragmentation and Consolidation (lot types): In the case of property size changes, I distinguish the management of the *lot*, a contiguous management area, from that of the household *property* which can aggregate several noncontiguous lots (Figure 5.1). *Lot fragmentation* and *consolidation* are important to measure the effects of property boundary changes on the spatial configuration of the landscape (study site).

b. Property Expansion and Reduction (property types): Property *expansion* refers to the acquisition of multiple lots over time, while *reduction* represents the divesting of property (Figure 5.2). The process of property *expansion* is important as a measure of a household's capacity to expand its landholdings; and the process of *reduction* as a measure of the inability of the household to maintain its original property size.

Table 5.1 Farmer, lot and owner typologies (1992–2002)

Typology of household farmers based on property ownership changes	Typology of farm-lots and household-owners based on changes in the size of the property	
Farmer type	Lot type	Owner type
<i>Changes in the ownership of the farm-lot</i>	<i>Changes in the size of a farm-lot</i>	<i>Changes in the size of the property held by a household</i>
<p>2002 sample</p> <ol style="list-style-type: none"> 1. Continuous Farmer – same household heads in 1992 and 2002 2. New Farmer Related – <i>Generational change</i>, land use decision making passed on to next generation, 3. New Farmer Unrelated – a new household has acquired the lot and/or management of the lot is now in hands of an unrelated household 	<ol style="list-style-type: none"> 1) Stable lot – (Lot type 1) 2) Lot Subdivision – The fragmentation of a lot, resulting in more than one property owner. Subdivision creates more than one lot out of the original lot (Lot type 2). 3) Lot Expansion – The expansion of an existing lot into contiguous land. Unlike property aggregation, lot expansion consolidates contiguous land into a management unit and thus has spatial implications that counteract the spatial subdivision processes (Lot type 3). 	<ol style="list-style-type: none"> 1) Stable property (Owner type 1 – Stable) 2) Property Reduction – The disaggregation of property by selling off parts of a property (Owner type 2 – Disaggregating property) 3) Property Expansion – The expansion of the number of lots an owner possesses. This occurs when land owners acquire additional land that is not necessarily contiguous to an existing lot (Owner type 3 – Expanding) 4) Property sold.
<p>1992 sample</p> <ol style="list-style-type: none"> 1. Same Farmer – same household heads in 1992 and 2002 2. <i>Generational shift</i> – household head is no longer in the sample frame in 2002 but the household remains in the same family – land use decision making will pass on to the next generation 3. Sold Out farmer – household that is no longer in the sample frame in 1992 		

Figure 5.1 Lot fragmentation and expansion processes (lot type)

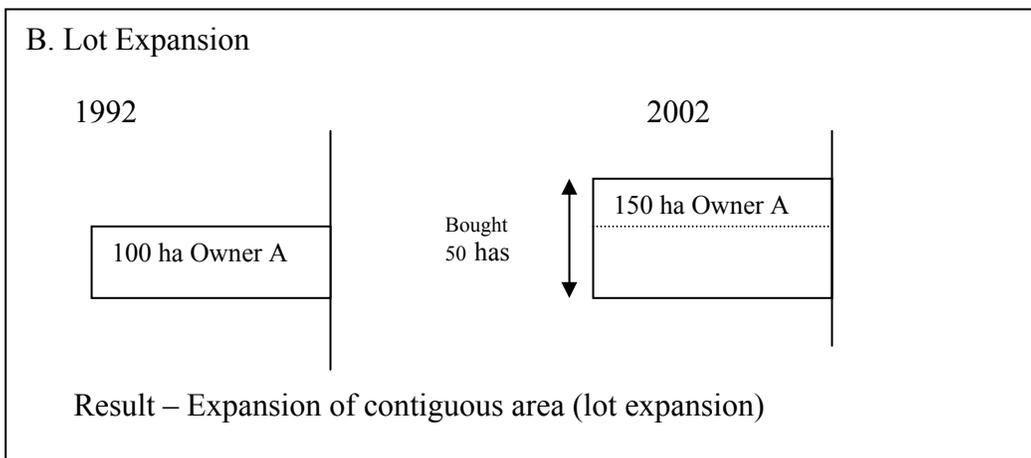
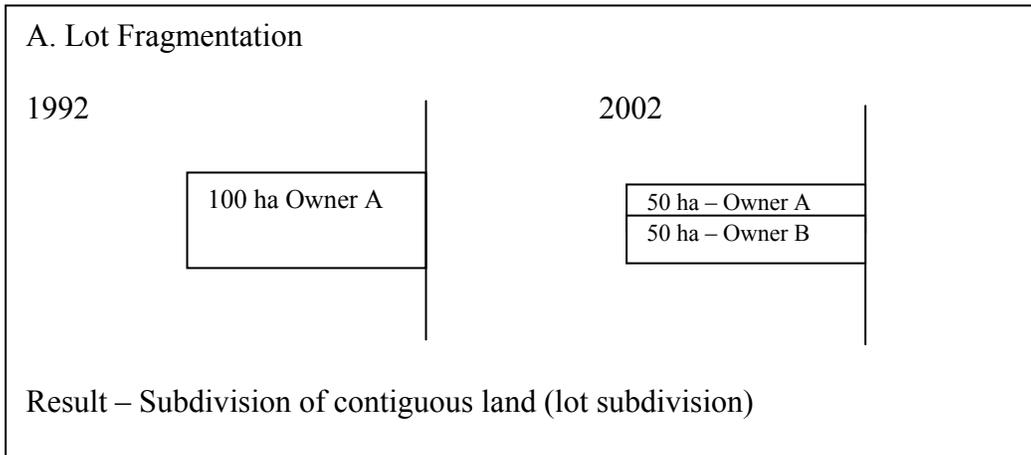
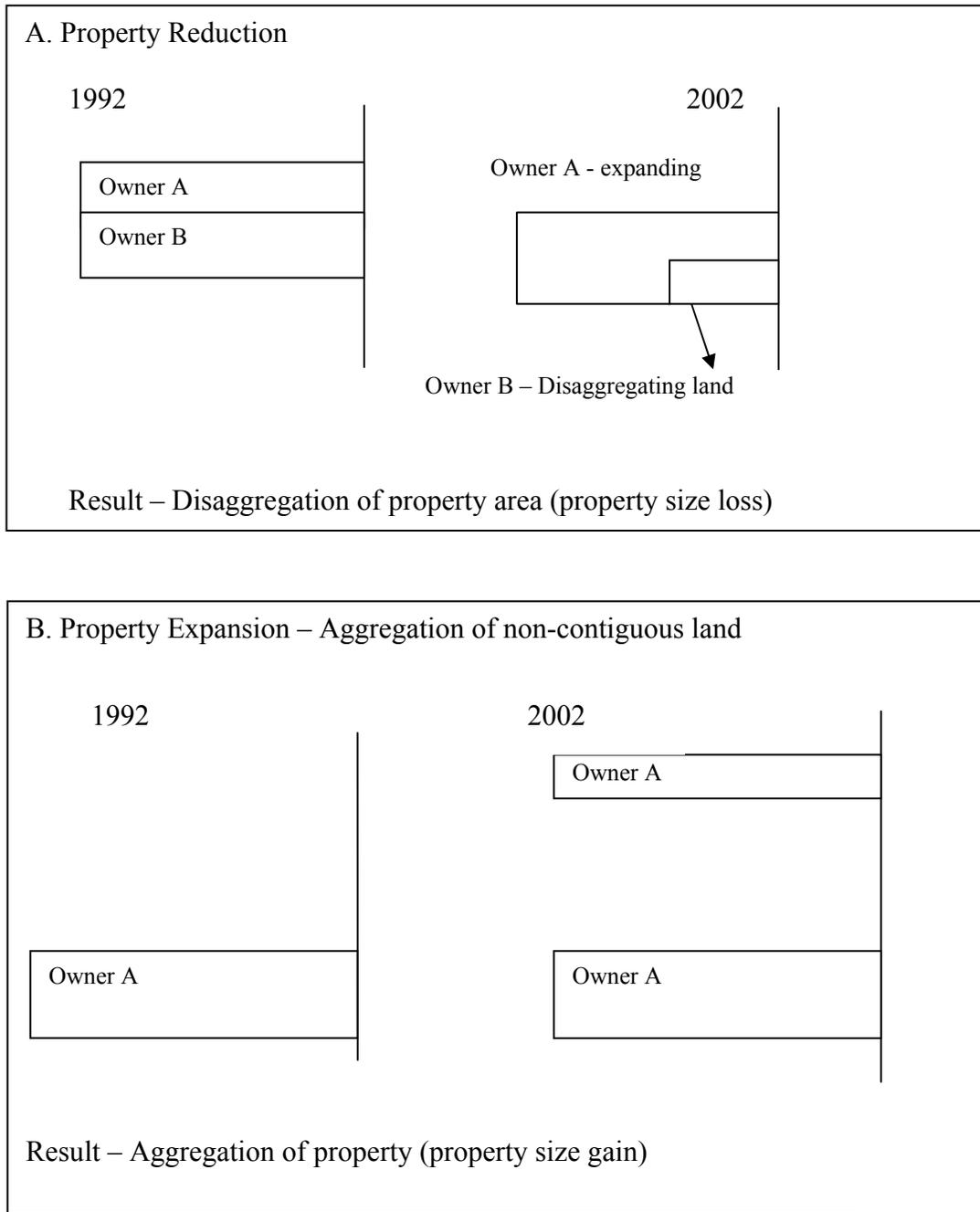


Figure 5.2 Property expansion and reduction processes (owner types)



Observations in the field and preliminary analysis suggested a very dynamic landscape over time, with some farmers consolidating lots while many others had subdivided or sold off lots in the study area. Consistent measures of these processes are

complicated by the diverse array of possible outcomes, e.g., multigenerational changes in ownership, the consolidation of land within the sample frame by farmers outside the original sample frame or the emergence of urban-based absentee land owners, among others. Additionally, there is no consistent specification of these variables in the literature. For example, Aldrich et al. (2006) do not explain how they differentiate new owners from continuous owners. They do not explain if new owners include the widows or sons of the original household head who might have taken over the management of the property. They also do not distinguish if new owners are new to the sample frame but long term owners of neighboring lots just outside the study area. These are important in light of determining the degree to which small landholder forms of production are able to maintain themselves in frontier regions or if they are being displaced by other kinds of farmers. In order to test for the degree of change in frontier land ownership processes, farmers have to be classified into more subgroups than in just continuous and new owners.

Several researchers within the political economy school, following trends in older agricultural frontiers in Brazil, predict that as the frontier becomes integrated into the larger national economy, capitalist forms of production will displace small landholders (Martins 1975; Foweraker 1981; Henkel 1982). Measurement of ownership and property changes over time and space should differentiate the peasant farmer mode of production from other forms of production (e.g., urban owners, large cattle ranchers). Is land being consolidated? And if so, is it by the original peasant farmers that established themselves in the region or by a new wave of land owners? Especially important is the need to measure the degree to which the land being consolidated is under small farmer mode of production, as distinguished from land being bought as a form of investment by urban owners, land speculators or corporate interests. Ozorio de Almeida and Campari (1995:1) determined that “speculative demand for land by a growing, prosperous Amazonian middle class is one of the important forces impelling growing numbers of small farmers to sell their plots and move on to settle temporarily and deforest new frontiers”. To test this hypothesis, the classification of farm owner types distinguishes rural farmers who live on the lot or on adjacent lots (rural residents), from those who are urban-based or

represent external interests such as large cattle ranchers or urban land speculators (urban-based owners).

Additionally, as many of the original settlers of old Amazonian frontiers begin to age, land owner classification should measure the effects of multigenerational changes on land use. Is the new generation of farmers behaving in the same way as the old generation? Moran (1984; 1989) and Findley (1988) emphasize the adaptation processes that correspond to the different stages through which Amazonian colonists pass. Brown and Muchagata (2004) have applied the concept of traditional knowledge to migrant colonists and shown how social learning processes are commonplace among recent or second generation migrants. Unlike their predecessors who were foreign to the region, the new generation of post-frontier heirs was brought up in and acculturated to the local environment. Has the post-frontier colonization setting created a new generation of Amazonian farmers that is more skillful in managing the land than their parents? Is the new generation of farmers brought up on the frontier as willing to invest in the frontier experience as their predecessors did or will they sell the land and move to urban centers? What are the implications of the generational change in land use as the new generation of farmers takes over?

Analysis

There are three sets of analyses performed on the panel group of smallholder farmers surveyed in 1992 and 2002. The first involves using descriptive statistics to characterize general patterns of population and property ownership changes between 1992 and 2002. The survey data from 1992 and 2002 are used to create frequency tables and graphs that portray changes in property ownership, property consolidation and fragmentation, and family farm structure over time. A Geographic Information System (GIS) was designed to analyze the spatial configuration of property boundary changes. GIS coverage of property boundaries was built for both 1992 and 2002, using information from field and satellite images. A detailed description of the methods to determine property boundaries, triangulating field maps drawn with the farmer, GPS points and satellite imagery analysis, is presented in Appendix A.

The second set of analyses identifies the importance of household life-cycle variables in explaining the processes of property consolidation and fragmentation and of changes in property ownership status. Households are classified into subgroups based on changes in the size of the properties (fragmented, consolidated or remained stable) and on changes of farmer property ownership (same farmer, new farmer related, new farmer unrelated). ANOVA and chi-square tests were used to measure differences among these subgroups of households for a set of theoretically important variables identified in the frontier development literature. Statistical differences between the profiles of the households within each of these subgroups identify the explanatory factors that constrain or facilitate these processes.

The third analysis is a regression model to test the significance of different household life-cycle variables in explaining changes in the size of the household's landholdings.

Descriptive Statistics

The following section presents a descriptive analysis, using empirical data from the panel data surveys (1992 and 2002) on changes and trends in the rural population and property landholdings. Specifically it looks at changes in demographic variables, lot and property sizes, property ownership and indicators of market integration.

Demographics and Population Change

In a post-frontier setting, I would expect to find the following demographic trends according to the household life-cycle theory: (1) a decrease in population over time, (2) a reduction in the dependency ratio (ratio of consumers to working-age adults within the household), (3) an increase in the number of nonfamily laborers living on the lot (*agregados* and *meeiros*)⁴⁸ and (4) an increase in the number of household members

⁴⁸ *Aggregados* and *meeiros* correspond to nonfamily households or members that live on the lot in exchange for labor or farm products. *Meeiros* are tied to an economic agreement in which they are allowed to live and use an area of the lot in exchange for half of all that he produces. *Agregados* also live on the lot but in exchange for their labor on the owner's farm. Both represent traditional forms of economic

working off-farm. Table 5.2 presents the major demographic features of the population for 1992 and 2002.

Table 5.2 Demographic changes (1992–2002)

Variable	1992	2002	% change
Number of families	374	303	-18.9%
Population (total)	1867	1226	-34.3%
Dependency Ratio	0.72	0.56	-22.2%
Density (persons/ha)	0.103	0.071	-30.5%
Number of empty lots	9	57	533.0%
Lots with multiple families	95	77	-18.9%
Lots with <i>agregados</i> or <i>meeiros</i>	59	27	-54.2%
Number of farms with family members working off-farm	62	60	- 3.2%

The longitudinal survey findings are mostly consistent with the trends that are expected in a post-frontier scenario except in the case of the number of *agregados* and *meeiros* and family members working off-farm jobs, both of which showed a percentage decrease instead of the expected rise in these percentage figures.

Life-cycle theory expects that as unremunerated working-family members move off the lot they will be replaced with nonfamily members (additional *agregados*, *meeiros* and the hiring of day-workers). The unexpected drop in the number of lots with *agregados* and *meeiros* can be explained by two parallel processes taking shape in the post-frontier: (1) modern economic forms of economic exchange whereby traditional sharecropping systems based on the labor force of *agregados* and *meeiros*, are replaced by direct hiring and daily wages, in fact the number of farms paying daily wages increased by 11.5 percent (table 5.8); (2) the decline of activities that require labor

relationships that were brought to the region from the large coffee estates in the southeastern region of Brazil. For our study I classify them as different types of sharecroppers.

intensive work, such as coffee harvesting, to less intensive production systems, such as cattle raising.

Despite the differences discussed above, overall population figures for the post-frontier region declined in accordance to frontier theories: The population of the study sites dropped by 34.3 percent, the dependency ratio by 22.2 percent, and population density by 30.5 percent. The most dramatic change was the increase in the number of lots that do not have anyone living on them (533 percent increase), a trend that was more obvious among lots closer to the larger urban centers (e.g., Rolim de Moura) when compared to the more distant ones (e.g., Alto Paraiso). This seems to contradict location theory postulates that would suggest more intensive land use classes closer the urban market center. However, although these lots are considered empty from a demographic perspective (no one actually lives on them), they are being managed by urban or neighboring lot owners in sometimes extensive forms of production, such as cattle raising, or sometimes just kept as a form of idle investment. The new context of urban growth in the region suggests a more diffuse urban-rural divide than is suggested in conventional geographical and economic theories and is the result of the modern transformation of the landscape which blurs this divide in the Amazon post-frontier period.

Lot and Property Size Changes

The household life-cycle hypothesis posits that small landholders' properties will eventually fragment and subdivide in order to accommodate the increasing number of family members that need land to farm. With ever decreasing farm sizes due to subdivision by inheritance, the resource base necessary to sustain each heir household is reduced, eventually rendering the farm unviable. Ultimately the heirs of the original lot liquidate their remaining farm property assets, and the process of land consolidation ensues. Thus the emergence of a consolidation stage is a testable hypothesis. Furthermore, different models vary in the form this consolidation stage takes (e.g., consolidation via successful pioneer farmers (and their heirs) or via external economic interests). Thus two alternative hypotheses emerge: (1) a consolidation stage emerges

because the most successful pioneer farmers expand and buy up most of the land while maintaining small-scale commercial production mixed with subsistence production, or (2) external economic interests, urban or based outside of the region, buy up most of the land, establishing large landholdings and substituting subsistence production with specialization in commercial products. The following two sections explore these questions by looking first at lot and property sizes and later at changes in ownership patterns.

Table 5.3 shows the frequency of lots that fragmented, expanded, and remained stable in size within the panel sample frame for the 1992–2002 period. Lots where part of the land was sold to a neighboring lot were classified as lot size reduction, while those that fragmented into more than one property (different owners in each fragment) were classified as lot fragmentation or subdivision. The lots which have undergone processes of size reduction or fragmentation (together comprising 19.0 percent) are more common than those that had expanded (10.9 percent). Not surprisingly, the consolidation of contiguous lots under one household occurs less frequently compared to the subdivision of lots among multiple owners. However, the most striking finding is that most lots (59 percent) remained stable; indicating that the processes of lot aggregation and subdivision are not dominant. Despite this assertion, the fact that 30 percent of the lots had unstable property boundaries during a 10-year period suggests that the emerging post-frontier is still a very dynamic space.

Table 5.3 Lot fragmentation and expansion

	1992	2002	1992 – 2002
Number of lots	220	239	
Lots reduced in size			12 (5.4%)
Lots that fragmented			30 (13.6%)
Lots that expanded in size			24 (10.9%)
Lots that remained stable			130 (59.1%)
Lots unaccounted for in 2002			24 (10.9%)

Descriptive statistics for the spatial distribution of lots between 1992 and 2002 shows that fourteen percent of the original sample frame fragmented between 1992 and 2002, increasing the number of lots within the sample frame from 220 to 239 households; the final sample frame in 2002 did not increase proportionally to the number of fragments due to a high level of household owners unaccounted for in 2002. Although some of the lots were bought by neighboring households already in the 1992 sample frame, most of these were bought by households from outside the original sample frame. However, in the next section (lot ownership changes) I will show that most of these new owners were not predominantly urban or external cattle ranchers but rather were successful farmers in the 1992 sample frame and in adjacent lots that acquired new land by 2002.

The patterns of property aggregation and disaggregation presented in table 5.4 are of equal importance to lot size changes. While changes in the lot size are important for analyzing changes in the spatial configuration of the landscape, the aggregation and disaggregation of total property holdings per household are important for determining which of the following hypotheses holds true in Rondônia: the persistence of pioneer households by fragmenting existing land among offspring or the accumulation of land by a handful of most successful farmers. While at the lot level, the most striking feature was the stability of the lot as a management unit (59 percent of lots remained the same size), at the household level (Table 5.4), there was a similar proportion for households that had remained stable (32.2 percent), that changed the size of their property holdings (37.7 percent) and that sold out or were unaccounted for after 10 years (30.1 percent).

Agglomeration of land becomes more important when considering property ownership rather than individual lots, with 19.3 percent of households in the sample frame in 2002 having expanded their property holdings during the last ten years (Table 5.4). This figure is considerably larger than the percentage of lots expanding, which was 10.9 percent (Table 5.3). This is because, unlike subdivision processes, the expansion of properties does not occur predominantly through acquisition of adjacent lots but through the subdivision of lots in the vicinity, or through opportunities across the landscape and sometimes beyond the study sites, in other frontier regions.

Table 5.4 Property aggregation and disaggregation

	1992	2002	1992–2002
Number of property owners	223	227	
Households with stable landholdings			72 (32.2%)
Households disaggregating land			41 (18.4%)
Households aggregating land			43 (19.3%)
Households that had sold all landholdings*			49 (22.0%)
Households unaccounted for in 2002			18 (8.1%)

* Although households that sold all their landholdings during the study period could not be interviewed in 2002, interviewers kept a record of which households had migrated to other places and which ones were not interviewed for other reasons by asking neighbors, etc.

The analysis of property size changes throughout the landscape shows that, unlike predominant models which stress the fragmentation and subsequent consolidation of landholdings, what seems to characterize the post-frontier is greater heterogeneity of farmer behaviors in regards to the size of their landholdings. The proportion of farmers able to remain viable with their original landholding size is equally important to trends of property fragmentation on the one hand, and on the other, to the consolidation of property ownership in noncontiguous areas. Overall the result is a trend towards the fragmentation of the landscape into smaller management units, even when consolidation processes are also occurring. The predominance of fragmentation processes increased the number of lots covered in the study area while the analysis also shows that the result of land ownership agglomeration is not consolidation of contiguous properties. On the contrary, agglomeration processes follow wherever fragmentation of land is occurring, leading to opportunistic accumulation of land rather than the planned consolidation of land into contiguous management units. The result is the continuous fragmentation of the landscape despite the parallel patterns of land accumulation across farmers is as common as those of land subdivision.

Land ownership changes

An analysis of land ownership changes during the study period can help determine the extent to which the smallholder farmer is able to persist as a viable economic unit of production in the Amazon region. Furthermore, since new deforestation fronts in the Brazilian Amazon are no longer exogenous, but are guided by intraregional migration movements, it is important to understand what guides high property turnover rates in established frontiers and how to suggest policies that can control these internal migration movements (Ozorio de Almeida and Campari 1995).

As reviewed above, frontier theories have suggested that as households reach the end of their life-cycle they will tend to fragment, becoming economically and ecologically unviable, eventually leading to the consolidation of land by larger landholders. However table 5.5 shows that in 2002 farmers belonging to the original households represent 71.8 percent of the sample frame in 2002 (same owners and new owners who are relatives of the 1992 owners). That is, the percentage of owners arriving to the study sites since 1992 was only 20.3 percent (however it could be a bit higher since there are 7.9 percent of households unaccounted for, which might include new owners that were not found for interviewing during the field research period). This seems to suggest that the most important trend has been the persistence of the farmer household, bringing into question many of the assumptions about the eventual decline of smallholder farmer sustainability in the post frontier setting.

Table 5.5 Property ownership changes (1992–2002)

Farmer Type (1992–2002)	Alto Paraiso	Nova União	Rolim de Moura	Total
Same owner in 2002	50 (56.8%)	49 (58.3%)	24 (43.6%)	123 (54.2%)
New owner relative of original owner	20 (22.8%)	13 (15.5%)	7 (12.7%)	40 (17.6%)
New owner not related to original owner	17 (19.3%)	20 (23.8%)	9 (16.4%)	46 (20.3%)
Unaccounted for in 2002	1 (1.1%)	2 (2.4%)	15 (27.3%)	18 (7.9%)
Total	88	84	55	227

Another way of examining the stability of property ownership is by looking at the number of fragmented lots that includes the original owner on one of its fragments. Table 5.6 shows the increase in the number of lots resulting from the fragmentation of the original 1992 sample frame and the percentage of original households that retained one of the subdivided lots. Table 5.6 indicates that between 50 and 60 percent of the original subdividing household usually retained one of the subdivided lots.

Table 5.6 Increase in the number of lots within the sample frame as a result of lot fragmentation

Study site	Number of lots fragmenting	Number of lots fragmented into	% of fragmented lots that retained original owner
Alto Paraiso	16	44	50%
Nova União	9	20	66%
Rolim de Moura	5	12	60%
Total	30	76	58%

Although the expansion of lots into larger contiguous properties suggests limited land consolidation; using the farmer as the unit of analysis, instead of the lot, increases the percentage of owners expanding their lots from 19.3 percent (Table 5.4) up to 22.5 percent (Table 5.7). Table 5.7 examines property agglomeration or expansion based on the analysis of the land owners instead of the lots. Property agglomeration, the expansion of landholdings that are not necessarily contiguous, shows that 22.5 percent of the property owners in the 2002 sample frame had expanded their landholdings during the study period. Moreover, more than half of the expansions, between 66 and 90 percent (mean 74.6%), were attributed to landholders in the original sample frame (continuous owners). Another 10 to 33 percent (mean 26.3%) of those landholders agglomerating properties are new owners.

Table 5.7 Property ownership expansion (1992–2002)

Study site	Number of owners expanding (1992–2002)	% of owners from the original sample aggregating land	% of owners aggregating land that arrived after 1992
Alto Paraiso	24 (30.8%)	16 (66.6%)	8 (33.3%)
Nova União	10 (11.8%)	9 (90.0%)	1 (10.0%)
Rolim de Moura	16 (26.7%)	12 (75.0%)	4 (25.0%)
Total	50 (22.4%)	37 (74.6%)	13 (26.3%)

In order to test the hollowing of the frontier hypothesis, that predicts the displacement of small landholders by larger capitalist interest and urban owners, new owners are classified as rural owners (lives on the lot or a neighboring lot) or absentee owners (urban owners or external ranchers that are expanding landholdings into the region). Contrary to expectation only one of the expanding owners was an absentee owner. However, this number may be underestimated due to the fact that information is extremely limited for absentee owners in our sample.⁴⁹ Most of the lots classified as

⁴⁹ Since the 2002 survey is based on the 1992 interviews, the descriptive statistics take into account those lots that were surveyed in 1992 but had absentee or urban-based owners in 2002, so the number and

unaccounted for in 2002 could be attributed to absentee ownership, increasing the percentage of lots that are owned by absentee owners to up to 8 percent of the sample frame. Despite this deficiency, by examining both who is acquiring the subdivided lots and who is agglomerating properties, it can be inferred that the majority of the subdivisions are acquired by the neighboring smallholder farmers themselves and not by external interests as presupposed in much of the critical political economy literature.

Property division in the last ten years has resulted in an increase in the number of households within the sample frame while overall population (number of families and persons living on the lots in the sample frame) decreased. This begs the question as to the overall demographic and population growth consequences of these processes on the post-frontier. If these are internally driven by small landholders within the post-frontier setting, the population would be expected to be either stable or growing due to its own reproduction rates. However, overall population has decreased despite an increase in the number of properties surveyed. Parallel processes that include migration to urban areas and the further movement of *agregados* to other sections of the economy (or towards their own piece of land) are not considered in conventional models and should be taken into account. Can populations on the frontier stabilize and shift property boundaries to accommodate the growing needs of succeeding generations? What are the repercussions of the new generation of smallholder farmers taking over their parents' lands? Are they willing to stay in the post-frontier setting despite a declining resource base? The following section considers some of these questions and explores changes in the characteristics of the population during the 10-year study period. First, however, the links between the evolution of the frontier change and markets will be explored.

Market integration

According to some life-cycle theorists, as households progress through their life cycle, the strength of their ties with the market increases (Murphy 1998; Walker et al. 2002). Market integration is important in the study of household life cycles because, as

percentage of "empty lots" could be calculated for 2002 based on the 1992 sample frame (table 5.3). The 8.2 percent of properties not accounted for in 2002 (table 5.4) are probably managed exclusively by urban owners.

market economies envelop rural households, demographic factors might become less relevant in explaining land use (Godoy 2001). This section examines the household life-cycle theory's supposition that as the life cycle progresses household reliance on the market economy also increases. The effects of market integration variables on land use are explored in the next chapter.

Using the life-cycle stages theory I would expect market indicators to increase over time. I use the following indicators (1) number of *diarias*⁵⁰ employed, (2) number and percentage of households with family members working in off-farm activities, (3) number and percentage of households owning an urban residence, (4) number and percentage of households having bank accounts and (5) percent of harvest of key crops marketed (vs. consumed).

Table 5.8 Market integration: Wage labor, off-farm labor, urban ownership, bank accounts and percentage of production marketed.

Variable	1992	2002	% change
Number and % of farms paying <i>diarias</i>	87 (37%)	97 (43.5%)	11.5%
Number of <i>diarias</i> – Mean (SD)	73.3 (76.0)	69.7 (89.7)	-4.9%
Number and % of farms with family members working off-farm	62 (29%)	60 (31%)	-3.2%
Number and % of farm owners living in urban areas	40 (16%)	59 (28%)	47.5%
Number and % of households with bank accounts	33 (15%)	66 (34%)	100%
Percentage of production marketed – Mean (SD)	57.4 (29.7)	70.5 (35.2)	22.8%

Table 5.8 summarizes the descriptive statistics of the variables that measure the influence of the market on household life-cycle theory. Most of these market-related variables changed as predicted. The percentage of farmers paying *diarias* increased from 37 percent to 43.5 percent of all households, although the mean number of *diarias* paid

⁵⁰ *Diaria* is the daily wage and a meal

per year remained relatively stable. The percentage of households that had family members working in off-farm jobs also increased, but slightly less, from 29 percent to 31 percent. The percentage of urban-based owners also increased from 16 percent to 28 percent while the percentage of households with bank accounts increased by 100 percent, from 15 percent to 34 percent. Finally, the mean percentage of production marketed increased from 57.4 percent to 70.5 percent, or a 23 percent increase. Although these trends correspond to conventional frontier theories, whereby the frontier become increasingly integrated to different regional and international markets, the influence of these variables on land use decision making remains to be tested.

This section has described the main characteristics of a ten-year panel data set of farmer households. It highlighted demographic and property ownership changes, comparing trends among the three study sites over the ten-year study period. This data set will be used in the next section to test hypotheses about the relationships between demographic and life-cycle variables on property ownership and property aggregation and fragmentation processes over time.

ANOVA and Chi-square Analysis

Browder et al. (2005) identified rural property ownership changes and property fragmentation and aggregation as important factors in deforestation, land use and socioeconomic stratification processes in the post-frontier. Despite the demonstrated importance, the authors concluded their paper by suggesting additional research is needed that helps explain these processes (Browder et al. 2005:17). Following their suggestion, the forthcoming sections are designed to analyze how the household life-cycle theory explains the observed patterns of property ownership and of property aggregation and consolidation. In order to test for the life-cycle theory, I use the following household life-cycle indicators as described in chapter 3; (1) *duration of residency*, (2) *age of household head*, and (3) *dependency ratio*.

Hypothesis related to property ownership dynamics

Based on the household life-cycle model (Figure 2.1) and on the decision making framework I designed (Figure 2.3) I formulate the following testable hypotheses concerning property ownership changes. By testing 1992 values the analysis refers to the household level variables that can help predict changes in property ownership that will occur in the following ten years. The farmer typology used to analyze the following hypotheses was presented in Table 5.1.

H1.1: The end of the household life cycle leads to a change of ownership management of the property. Households that have undergone property ownership changes (household farmer types 2 and 3) will have been closer to the end of their life cycle in 1992 than those that remained stable (household farmer type 1). Therefore, **in 1992, household farmer types 2 and 3 will be associated with more years of residence in Rondônia, an older household head, and a lower dependency ratio than farmer type 1 households.**

H1.2: Although both household farmer types 2 and 3 undergo ownership changes, the difference between a household maintaining a property (farmer type 2 - generational change) and selling out (farmer type 3 - leaving the area), depends on the household demographic composition and size of the total landholdings with which the household reaches the end of its life cycle⁵¹. **In 1992, farmer type 2 households will have more available adult labor, larger landholdings and a lower dependency ratio than farmer type 3 households** when they reach the end of their life cycle.

H1.3: As postulated by Moran (1989, 2003) I hypothesize that within a cohort of farmers, those that arrived on the frontier first had a significant advantage over those who started production later within the same frontier region⁵².

⁵¹ Households that were interviewed in 1992 and were not found in 2002 are considered to have “sold out”. To confirm this hypothesis a subsample of these were revisited in 2003 for interviews about the previous owner, asking the current owner, neighbors and older residents who confirmed that most of the households that could not be interviewed in 2002 had moved out to one of the growing urban centers in the region, or further along the frontier to areas that are opening up in Northern Mato Grosso and southern Amazonas.

⁵² Moran (2003) found that settlers who arrived earlier were able to choose the sites with the best soils and therefore, these lots have a significantly lower probability of entering the real estate turnover pool.

Therefore, even if both farmer types 2 and 3 are in the same life-cycle stage in 1992, **farmer type 2 households have had their lot for a longer period of time, permitting them to accumulate more wealth and land over time and therefore are more able to survive the generational shift.**

In order to test the proposed hypotheses, 1992 indicators of the household life cycle were tested using ANOVA and chi-square tests comparing the variables across the three groups of household farmer types (Table 5.1). By using the 1992 variables to test for farmer classification types based on household changes for the period of 1992 to 2002, I can infer direction of causality of the household life-cycle variables in explaining changes during the next ten years.

Table 5.8 summarizes ANOVA and chi-square results, comparing household life-cycle variables across the three groups of farmer household types. ANOVA tests confirm hypothesis 1.1 for those households that suffered a generational shift but not for those households that sold out. As expected, farmer type 2 households have a significantly older household head than farmer type 1 households, but the same was not true between farmer type 3 and type 1 households. Similarly, farmer type 2 households had a significantly longer duration of residence than farmer type 1 households but not so for farmer type 3 households. Finally, households that suffered a generational change also presented a significantly lower dependency ratio in 1992 than farmer type 1 households. Farmer type 2 households, those that experienced a generational change, seem to confirm hypothesis 1.1 whereby, in 1992 they were further along their life cycle than farmer type 1 households, while this doesn't seem to be the case of those households that sold out. Since farmers that sold out between 1992 and 2002 could not be associated with life-cycle indicators as were households associated with a generational change, other factors seem to be more important in explaining household survival than the life-cycle stage.

Table 5.9 ANOVA and chi-square tests of household life-cycle variables (1992) across household Farmer Types classified according to property ownership changes (1992–2002)

	Farmer Type 1 same farmer (n = 93)	Farmer Type 2 generational change (n = 20)	Farmer Type 3 farmer who sold out (n = 40)
Number of families	1.94 ± 1.1	2.30 ± 1.2 ^c	1.63 ± 0.6 ^b
Total persons living on the lot	10.72 ± 5.6 ^c	10.6 ± 5.9	8.23 ± 6.6 ^a
Persons between 16–65 years of age (Adults)	6.17 ± 3.6 ^c	7.5 ± 4.1 ^c	5.1 ± 3.6 ^{a,b}
<i>Aggregados</i>	1.04 ± 1.8	0.5 ± 1.2	1.1 ± 2.5
Dependents	3.97 ± 3.1 ^c	3.1 ± 2.5	2.1 ± 1.7 ^a
Men (Adults)	2.00 ± 1.3	2.2 ± 1.2	1.54 ± 0.98
Women (Adults)	1.49 ± 0.91	1.80 ± 0.83 ^c	1.27 ± 0.69 ^b
Children	2.86 ± 2.02 ^b	1.15 ± 1.04 ^a	2.05 ± 1.9
Elderly	0.05 ± 0.228 ^c	0.15 ± 0.489	0.19 ± 0.4 ^a
Dependency Ratio	1.062 ± 0.87 ^b	0.38 ± 0.42 ^a	0.86 ± 0.79
Years in RO	14.4 ± 4.5	13.7 ± 4.7	14.3 ± 4.22
Residence years in lot	9.7 ± 5.2 ^b	12.6 ± 4.4 ^{a,c}	9.1 ± 5.8 ^b
Age of household head	45.3 ± 11.5 ^b	53.3 ± 14.3 ^a	48.6 ± 14.7
Area of lot (has)	85.6 ± 34.2 ^c	80.2 ± 24.5	72.3 ± 32.0 ^a
Off-farm income	28 (30 %)	4 (20 %)	9 (23 %)
<i>Diarias</i> (wage labor)	39 (43 %)	8 (42 %)	11 (31 %)
Urban property	22 (24 %)	3 (15 %)	9 (23 %)

Significance difference at the 5% level

- a) significantly different from farmer type 1
- b) significantly different from farmer type 2
- c) significantly different from farmer type 3

The results of table 5.9 confirm hypotheses 1.2 and 1.3, suggesting that farmer type 3 households were forced to sell their land due to demographic (higher dependency ratio and lower number of adult workers) and physical (area of lot) constraints while farmer type 2 households were able to pass their lot on to the next generation. Comparison of mean estimates between farmer type 2 and type 3 households for the number of working-age adult members' show that this was significantly lower for farmer

type 3 households, suggesting adult workforce was a crucial factor for survival of the household in the frontier. However, the dependency ratio, was, as expected higher, but it was not significantly higher, suggesting that the total adult workforce was more important in explaining property size changes than securing subsistence needs. Finally, the total area was lower but not significantly different for farmer type 3 households compared to farmer type 2 households. In regards to hypothesis 1.3, results confirm that the duration of residence was significantly important in explaining farmer survival on the frontier since farmer type 3 households had a significantly lower number of years in the frontier than farmer type 2 households.

It can be concluded that household changes in property ownership within the same household, a generational shift, are linked to the life cycle of the household, but this does not hold true for those households that sold off and moved elsewhere. Also, some household life-cycle indicators, such as household head age, were more important than others, such as the dependency ratio and the number of years in Rondônia. ANOVA tests found that farmer type 2 households had significantly older household heads and number of years in Rondônia than farmer type 1 households, positioning them further along in the life cycle. ANOVA tests also found significant differences between farmer type 2 and type 3 households when comparing adult labor force and residence time on the lot, constraining the ability of farmer type 3 households to survive.

Hypothesis Related to Property Size Dynamics

While at the landscape level frontier theories predict the progressive reduction of the population (which seems to be the case in the Rondônian post-frontier), at the household level some properties may become overpopulated as their households reach the end of their life cycle. Using the modified household life-cycle model (Figure 2.3) I speculate that property fragmentation and consolidation are responses of households reaching the end of their life cycle to an increased number of families on their property. A household's response to this increase includes either one of the following scenarios: (1) the household does not have the capacity to expand their landholdings and is forced to subdivide the available land among the growing number of families on the lot, (2) the

household has been relatively successful and decides to invest in more land, aggregating landholdings perhaps to keep their family members in the vicinity, and (3) the household decides to sell out completely and migrate to new frontier regions or urban centers where they can start anew, taking the whole extended family with them.

Drawing on the household life-cycle model and the typology of farmers characterized by changes in the size of their property, I propose the following hypotheses:

H2.1: Fragmentation and consolidation of properties are processes triggered by the conditions inherent in the household demographic structure as it reaches the end of its life cycle, characterized by an increase in the number of families requiring land of their own. Households that are consolidating, fragmenting or selling their land are further along in their life cycle than those households that remained stable. Therefore, **owner types 2, 3 and 4 households have longer residence time on the lot, more years living in Rondônia, an older household head, and a lower dependency ratio than owner type 1 households.**

Furthermore, the conditions that determine if a household consolidates, fragments, or sells its landholdings are determined by the demographic structure of the household and its accumulated capital assets when it reaches the end of its life cycle.

H2.2: Households expanding land reach the latter stages of their life cycle under more favorable demographic conditions and with better capital assets than those that are forced to fragment or sell. **In 1992, owner type 3 households had lower dependency ratios, a larger number of working adults, larger property holdings, and higher probability of owning an urban property and receiving off-farm income than owner type 2 and type 4 households.**

Following the findings of Moran et al. (1989) on the links between adaptability, the learning accumulation curve of a farmer and the household life cycle, I also test for the hypothesis that those households that have had the opportunity to adapt to their new

environment for a longer period of time will have a comparative advantage in the latter stages of their life cycle.

Therefore:

H2.3 Households that have been able to stay on the lot for a longer period of time, thus capitalizing on their labor and on the learning accumulation curve for a longer period of time, are more likely to reinvest part of their capital in acquiring more land. **In 1992, owner type 2 and 4 households have a shorter residence time on the lot and fewer years in Rondônia than owner type 3 households.**

I used the 1992 data set to consider direction of causality when examining differences in life-cycle variables between households classified according to changes in the size of their landholdings during the period from 1992 to 2002.

Table 5.10 summarizes the results of ANOVA and chi-square tests. I reject the first hypothesis in light of the fact that the four 1992 variables that position the household along its life cycle; *household head age*, *residence years on the lot*, *years in Rondônia* and *dependency ratio* for owner type 1 households, are not significantly different from the other household owner types. Therefore, the alternative hypothesis that all household types are in comparable life-cycle stages would have to be accepted except for owner type 3, or expanding households. Contrary to expectations, the life-cycle positioning variable locates them at an earlier stage in their life cycle compared to owner type 1, or stable households. Furthermore, owner type 3 *household heads* are also significantly younger than heads of other household owner types. This could suggest a later migration group not contemplated in the household life-cycle model and is further explored in the discussion section below.

By rejecting hypothesis 2.1 we are forced to reject hypothesis 2.2 since it assumed that those households that aggregate land (owner type 3 households) had reached the end of their life cycle. Field data analysis found the opposite; that households expanding their property were at an earlier life-cycle stage than non-expanding households. However an examination of the differences in demographic variables between household owner types

found that there are important differences in their demographic structure that might affect subsequent property size changes. From table 5.10 it can be concluded that unfavorable demographic conditions (lower number of total working adults, lower number of adult working men) and smaller lot sizes favored the survival of farmers with stable properties (owner type 1 households) over those households that sold their lands (owner type 4 households). Furthermore, the number of families was significantly higher in 1992 for properties that eventually fragmented (owner type 2) compared to households that eventually sold their property. An alternative hypothesis can be suggested whereby the demographic household structure and not the life-cycle position of a household is more important in explaining differences between stable (owner type 1), fragmenting (owner type 2) and farmers who sold off their lands (owner type 4).

Table 5.10 also suggests that hypothesis 2.3be rejected for owner type 3 households but not for owner type 1 households. Expanding lots (owner type 3), out of all the owner types, had a significantly lower number of *residence years on the lot* and *years in Rondônia*, suggesting that perhaps expanding farmers belong to a later migration wave. Furthermore, assuming that land is a measure of the relative success of the household on the frontier, *years on the lot* and years in the region (in this case the variable *years in Rondônia*), as suggested by Moran (1989) and Ozorio de Almeida and Campari (1995) were not found to be good predictors of wealth accumulation.

On the other hand, stable households (owner type 1) have a longer residence time on the lot and years in Rondônia than owner types 3 and 4 households reaffirming that hypothesis 2.3 holds true for stable households (owner type 1), but not for expanding households (owner type 3).

Table 5.10 ANOVA and chi-square tests of life-cycle variables (1992) across owner-type households classified according to property size changes (1992–2002)

(1) household with stable landholdings, (2) household disaggregating land, (3) household aggregating land and (4) household that sold off all landholdings.

Household-level variables	Owner Type 1 n = 72	Owner Type 2 n = 41	Owner Type 3 n = 43	Owner Type 4 n = 49
Number of families	2.07 ± 1.2	2.2 ± 1.3 ^d	1.72 ± 0.8	1.63 ± 0.6 ^b
Persons living on the lot	10.7 ± 5.9 ^d	11.2 ± 6.2	9.1 ± 5.7	8.23 ± 6.6 ^a
Between 16–65 years of age (Adults)	6.6 ± 3.8 ^d	7.3 ± 4.3	5.3 ± 3.1	5.1 ± 3.6 ^a
<i>Aggregados</i>	0.98 ± 2.4	0.41 ± 1.0	1.38 ± 2.2	1.38 ± 3.5
Dependents	4.05 ± 3.1	3.9 ± 2.8	3.8 ± 3.7	3.2 ± 4.1
Dependency ratio	0.79 ± 0.91	0.62 ± 0.44	0.80 ± 0.69	0.71 ± 0.60
Men (Adults)	2.2 ± 1.3 ^d	1.92 ± 1.3	1.93 ± 1.1	1.53 ± 0.97 ^a
Women (Adults)	1.5 ± 0.7	1.65 ± 1.0	1.4 ± 1.0	1.3 ± 0.7
Adults	3.7 ± 1.7 ^d	3.6 ± 1.9	3.3 ± 1.8	2.8 ± 1.5 ^a
Children	2.7 ± 2.1	2.4 ± 2.0	2.5 ± 1.8	1.97 ± 1.8
Elderly	0.1 ± 0.4	0.04 ± 0.2	0.7 ± 0.25	0.16 ± 0.4
Dependency Ratio	0.93 ± 0.8	0.91 ± 0.96	1.0 ± 0.9	0.9 ± 0.85
Years in RO	15.3 ± 4.0 ^c	14.1 ± 5.1	12.7 ± 4.9 ^a	14.3 ± 4.2
Residence years on the lot	11.6 ± 4.6 ^{c, d}	11.9 ± 4.6	7.1 ± 5.3 ^a	9.1 ± 5.7 ^a
Age of household head	49.0 ± 11.1 ^c	48.5 ± 11.7 ^c	41.2 ± 11.8 ^{a, b, d}	48.6 ± 14.7 ^c
Area of lot (has)	87.2 ± 22.3 ^d	79.1 ± 27.2	80.6 ± 43.6	71.7 ± 32.2 ^a
Off-farm income	20 (35 %)	6 (23 %)	6 (20 %)	9 (22 %)
<i>Diarias</i> (wage labor)	21 (36 %)	12 (46 %)	14 (48 %)	11 (28 %)
Urban property	11 (19 %)	6 (23 %)	9 (31 %)	9 (22 %)

Significance difference at the 5% level

- a. significantly different from owner type 1
- b. significantly different from owner type 2
- c. significantly different from owner type 3
- d. significantly different from owner type 4

These analyses have statistically compared the different household life-cycle variables across groups of farmers classified according to changes in property ownership

and in the changes in the total size of the landholdings. This served to test hypotheses regarding the effect of these variables on the dynamic changes that characterize the post frontier landscape. However, they cannot attribute a cause-effect relationship between these variables and the dependent variable. The next section attempts to create a regression model that can test for the explanatory power of household life-cycle variables by establishing a cause-effect relationship between these variables and the total size of the family's landholdings.

Regression analysis

In order to assess the role of household life-cycle variables in determining property size changes (consolidation and fragmentation of properties) I ran several regression models to test for the cause-effect relationships of these variables with the change in the size of the property. As explained in the previous sections, the household life-cycle theory does not explicitly address how life-cycle stages affect changes in the size of a household's landholdings, but one can extrapolate from it to design a testable model (Figure 2.3).

The model posits that those households that are fragmenting and expanding landholdings are both in the latter stages of their life cycle. Thus, land fragmentation and aggregation are both different processes triggered by the same event, the end of the life cycle and the generational transition phase. The model also specifies that the process (aggregation or disaggregation) a household follows is a function of the accumulated wealth and demographic structure with which the household reaches the end of its life cycle. However, ANOVA tests in the previous section suggest that expanding households were not located in the latter stages of their life cycle. Still, demographic and other household characteristics showed differences between the different owner types. I ran regression models to test the following hypotheses.

Hypothesis 1: Demographic and household level factors in the latter stages of the life cycle determine the degree to which households aggregate, disaggregate or are able to maintain a stable landholding.

Dependent variable – Change in the size of the property or total landholdings (2002 – 1992)

Hypotheses related to Property Subdivision

H3.1 Households in an advanced stage of their life cycle (older household head) have higher frequency of property subdivision than households in an earlier stage (younger household heads). Independent variable: age of household head in 2002

H3.2 Households in an advanced stage of their life cycle (with **fewer resident working-age related family members**) have a higher frequency of property subdivision than younger households with offspring still residing and presumably working on-farm. Independent variable: number of resident working-age related family members in 2002.

H3.3. Households that have a higher dependency ratio (dependents/working-age adults) at the beginning of the study will have a higher frequency of property subdivision than households with lower dependency ratios. Independent variable: household dependency ratio in 1992

Dependent variable – Change in the size of the property (2002 – 1992)

Hypotheses Related to Property Accumulation

H3.4 The longer a household resides in the region the more it increases its capital assets and enlarges its total landholdings. Independent variable: length of residence in Rondônia.

H3.5 Households composed of larger number of working-age members will enlarge their total landholdings. Independent variable: number of working-age members (adults 16-65 years old) in 1992.

H3.6 Households that have been able to stay for a longer period of time on their farm properties will have larger total land holdings than farmers with shorter periods of residence. Independent variable: length of residence on current farm lot.

H3.7 Households with larger proportions of their landholdings converted into production at the beginning of the study period will enlarge their total landholdings. Independent variable: area deforested in 1992

Since I am testing for the impact of household demographic variables on the change in size of household landholdings, I limited my analyses to those households who have acquired or disaggregated their landholdings during the last ten years (owner types 2 and 3). I further limited the analyses to those households that were surveyed in both years. Note that this includes both new and old owners as long as they belong to the same household in both surveys (household farmer types 1 and 2). This reduced the total sample frame to 60 households. Table 5.11 presents outcome and independent variables names, their operational definition, descriptive statistics and correlations.

Table 5.11 Descriptive statistics for change of landholdings size (1992 – 2002) and explanatory demographic factors, Rondônia, Brazil (n=60).

Variable Name	Operational Definition	Mean	Standard Deviation	Correlation with change in size
<i>Outcome variable</i>				
Change in size (1992 – 2002)	Natural log (ln) of the change in the size of the landholdings in hectares <i>Ln (150 + change in size 02 – 92)</i>	5.0679	0.3409	1.000
<i>Independent variables</i>				
Age of household head (2002)	SQRT of the age of the head of the household in 2002 <i>Sqrt (72 – age of household head)</i>	4.5634	1.1681	-0.098
Working-age offspring or related family members (2002)	SQRT of the number of family members between 16 and 65 years of age in 2002 <i>Sqrt (number of persons between 16-65 in 2002)</i>	1.6832	0.4533	0.241
Household dependency ratio (1992)	SQRT of the ratio of working-age members (16-65 years old) over the number of dependents (family members younger than 16 and older than 65) <i>Sqrt (dependency ratio in 1992)</i>	0.8580	0.5051	-0.003
Years living in Rondônia (2002)	Number of years the household head has lived in Rondônia (2002)	23.02	4.549	-0.154
Working-age members (1992)	SQRT of the number of persons living in the lot between 16 and 65 years of age in 1992 <i>Sqrt (number of persons between 16-65 in 1992)</i>	2.3231	0.8054	-0.271
Years on lot (2002)	Square root (SQRT) of the number of years on lot in 2002 <i>Sqrt (33 – years on lot)</i>	3.3236	0.8236	0.254
Deforestation IGSCR (1992)	Area of the landholding deforested in hectares until the year 1992 measured with IGSCR remote sensing technique	45.5562	22.9123	0.267

Independent variables consider six household demographic variables (*age of household head, number of working-age offspring-related workers, household dependency ratio, years living in Rondônia, number of working-age members in 1992 and years on the lot*) and one resource availability indicator (*deforestation in 1992*) that are hypothesized to affect changes in the size of a household landholdings over time.

Data screening led to the transformation of outliers within each independent variable. One multivariate outlier was eliminated, reducing total number of observations from 60 to 59. Evaluation of independent variables for normality, linearity and homoscedasticity assumptions led to the square root transformation of *age of household head*, *working-age offspring-workers*, *household dependency ratio*, *working-age members* and *years on lot*. Furthermore, since *years on lot* and *age of household head* had negatively skewed distributions, each original value was subtracted from the highest existing value plus one; a constant of 33 in the case of *years on lot* and 72 in the case of *age of household head*. The dependent variable (*change in property size*) also had to be normalized using a Neperian logarithm and adding a constant of 150 to each value in order to eliminate all negative values.

Table 5.12 presents the results of Ordinary Least Squares (OLS) models for the change in the size of the household landholdings regressed on the household demographic variables and initial deforestation. Four regression models were tested; model 1 presents results for the six household demographic variables and the initial deforestation variable, model 2 presents the same six household demographic variables excluding the deforestation variable, model 3 selects for only disaggregating households (21 observations) focusing on the three independent variables in hypotheses H3.1, H3.2 and H3.3, and model 4 selects for only aggregating households (n=39) testing for the three independent variables in hypotheses H3.4, H3.5, and H3.6. In the case of models number 3 and 4, the initial deforestation value, *area deforested in 1992*, is also included in the model.

Table 5.12 Regression models of the change in the household's landholding size (1992–2002) regressed on household life-cycle variables and initial deforestation.

	Model (1) All	Model (2) All	Model (3) Owner type 2	Model (4) Owner type 3
Constant	5.081	5.314	5.139	5.210
Age of household head (2002)	-0.055*	-0.063*	-0.022	
Years living in Rondônia (2002)	-0.004	-0.005		-0.012
Years on lot (2002)	0.081*	0.067		0.015
Working-age related family members (2002)	0.137*	0.165*	-0.006	
Working-age members (1992)	-0.115**	-0.111**		0.079
Household dependency ratio (1992)	-0.040	-0.152	0.057	
Deforestation IGSCR (1992)	0.003*		-0.009*	0.002
F value	2.886**	2.862**	1.075	1.259
R ²	0.305	0.259	0.223	0.148
R ² adj	0.199	0.169	0.015	0.030
N	59	59	21	39

* p < 0.15, ** p < 0.05, *** p < 0.01

The first model presents significant coefficients for *age of household head*, *working-age related family members in 2002*, *working-age members in 2002*, *years on lot* and *deforestation in 1992*. Therefore, pooled samples of aggregating and disaggregating properties showed that small landholders were more prone to enlarge their landholdings if 1) they have an older household head, 2) they had more working-age members on the lot in 2002, 3) they had fewer working-age members in the lot in 1992, 4) they had spent less years living on the lot, and 5) they had larger areas of their property deforested in 1992. If the initial deforestation variable is removed the significant effect of the variable *years on lot* disappears but all other significant variables remain unchanged. Despite significance of numerous household life-cycle variables, the models accounted for only 20 percent of variance of the change of a property's size in the case of model 1 and 17 percent in the case of model 2. Models 3 and 4 were not statistically significant.

Overall, hypotheses 3.3 and 3.4 would have to be rejected since no significance was found between these variables and a change in the size of the landholdings. Models 1

and 2 confirm hypothesis 3.1 whereby older household heads are more inclined to enlarge their landholdings. These models also confirm hypothesis 3.2 which states that fewer resident working-age related family members (and thus families that are further along in their life cycle) are associated with higher frequencies of property subdivisions. Contrary to what was hypothesized, models 1 and 2 show that households with lower numbers of working-age members in 1992 were more prone to enlarge their landholdings during the study period than households who had more adult members in 1992. In the case of hypothesis 3.6, model 1 confirms the hypothesis that households that have been on their lot for a longer period of time will have larger total landholdings at the end of the study period than other households. Similarly, models 1 and 3 confirm the impact that higher initial deforestation levels on the lot have on changes in the size of the household landholdings. Model 1 shows that those households that had deforested a larger area of their lot in 1992 would enlarge the most during the study period. On the other hand, by selecting only those households that had disaggregated their landholdings during the study period, regression results showed that those households that had deforested a larger portion of their lot in 1992 had a higher frequency of property subdivision during the study period than otherwise.

Summary and conclusions

The objective of this chapter was to identify some of the most important household-level factors that contribute to explain land use change and property ownership patterns, specifically those that can decrease farmer turnover on plots and increase farm-size stability. The hypothesis was that the household life-cycle variables would explain land ownership changes and changes in the size of the properties. A model based on the household life-cycle theory specified the factors that lead to ownership and property size changes, linking these changes to the end of the household life cycle (Figure 2.3). However, the results from ANOVA and Chi-square tests, as well as regression models, did not support these hypotheses, suggesting other variables were more important.

This research has also shown that the rates of property turnover and property fragmentation and consolidation were in fact not as widespread as hypothesized. Still they were within the values found in other studies of the Brazilian Amazon and therefore

important factors to consider for stabilizing existing frontiers and mitigating deforestation in new frontier zones (e.g., Ozorio de Almeida and Campari 1995). However I could not conclude that property turnover and property size changes were due to the demographic characteristics associated with the end of a household's life cycle. The relationships between these processes and the demographic characteristics of the household were far more complex. Perhaps the most important conclusion from this chapter is that we cannot rely on the household life-cycle theory alone to understand changes at the property level, and that perhaps this has to be analyzed within the particular historical process and site specific characteristics of the region studied.

Another conclusion with implications for understanding the emerging post-frontier is the fact that no predominant pattern was found for the variables studied. Actually, considering the lot (physical boundaries of a continuous piece of property) as the unit of analysis, the predominant trait was its stability over time. When I considered the property of a household as the unit of analysis, that is, all a household's landholdings regardless of their spatial connectivity, trends were equally distributed between property aggregation, disaggregation and stability. Property fragmentation and property ownership patterns studied show that differentiation and heterogeneity were more important than any single overarching process.

The complex and dynamic spatial reconfiguration of property patterns found in the study area has important implications for land use change studies, especially for those designed with methodologies based on the false assumption of a stable configuration of properties. This false assumption has led studies to use grid-like overlays on satellite images to study land use change, assuming a relatively stable grid of property boundaries over time and that lots represent the property distribution of individual households (Brondizio et al. 2002; Caldas et al. 2002; Moran et al. 2003). Evidence from the Rondônia landscape suggests otherwise. The population of farmers in our study sites showed that over one-third of the sample has aggregated, sold off or subdivided their lot during the study period and that these changes were not always represented spatially on contiguous lots. Studies that assume a household is represented by a contiguous lot is misspecifying the unit of analysis at the household level, especially in a post-frontier period.

To the question of which household response predominates at the end of the household life cycle, an empty nester scenario, whereby young adults leave the household or a generational shift whereby grown children remain on the farm to build their own families, I would have to claim both have become equally important in Rondônia. This differs from the Ecuadorian post-frontier region where property fragmentation is the only response to increasing demographic pressure from within the household since no more land is available. In Rondônia, interviews revealed that households are linked socially (through friends, extended family members) and economically (through remittances, land investments) to new frontier areas in Rondônia and neighboring states (e.g., Northern Mato Grosso and Southern Amazonas) expanding the possibility of total or partial migration in order to maintain their present living standards. Figure 2.3 attempts to capture this complexity. Land use outcomes of these decisions will be explored in the next chapter.

On a broader scale, these results also have theoretical implications for frontier theories, especially for political economic frameworks. Early Amazonian frontier theories have usually predicted the displacement of initial settlers by capitalist economic interests (Martins 1975; Foweraker 1981) or serving the accumulation of capital elsewhere (Goodman et al. 1984). Results show a more heterogeneous reality. On one hand property turnover was low; small landholders' survival rate was as high as 78 percent. This percentage is higher than the 64 percent found by Ozorio de Almeida and Campari in their panel data set study for a ten-year period in Para and Mato Grosso (1995). On the other hand, those that were displaced were mostly bought out by neighboring rural owners and not external economic or urban-based interests, which represented only up to 8 percent of all properties. Another 20 percent of the sample frame had been bought by expanding neighboring rural owners. This brings into question the belief of a capitalist take-over and their displacement by other types of economic interests, suggesting instead that what predominates is the persistence and survival of the small landholder.

While examinations of property ownership changes seemed to suggest the changes were endogenous to the frontier, the profile of expanding households present a different picture. Results showed that expanding households were younger, had arrived later in Rondônia and had bought the lot much later than the other types of households.

The significantly different farmer profile and the fact that they are the farmers that are increasingly expanding their landholdings suggest that they correspond to a younger generation of owners who arrived in the study area later and with more resources than the original pioneers. Ozorio de Almeida and Campari (1995) found the same trends in Mato Grosso and Para suggesting many were not farmers at all, but rather merchants, public servants, and other city dwellers. Furthermore, this younger cohort appears not to be interested in farming but in concentrating land and expanding pasture. The appearance of new owner types that do not correspond to conventional farming households further adds to the complexity of land cover trends in the frontier and the difficulty of finding an overarching theory that can explain them.

While I find support for suggesting the persistence of the small landholder rather than its demise, I also find more and more support for increasing social differentiation processes among small landholders which is also a reflection of the increasing heterogeneity and complexity of the population in the post-frontier. The results show that those households that sold off their lands had an unfavorable demographic structure to start with, explaining in part their eventual migration out of the sample frame. Additionally, households that are aggregating land had a significantly different farmer profile; younger and arriving on the lot and in Rondônia in a much more recent migratory wave. While I cannot conclude that the household life cycle has an impact on property ownership and property size changes I can conclude that as the frontier ages it becomes increasingly more complex and heterogeneous. What is less clear, however, is whether social differentiation processes found on the frontier would eventually lead to a class-based society or if social mobility of the emerging rural elite is constrained, as Karl Kautsky (1988) speculates, by the limits of the agricultural sector itself as it evolves within a capitalist economy.

The analysis in this chapter of demographic and property changes over time confirms the complexity and dynamic nature of post-frontier Amazonia. These results seem to be more in line with the observations outlined by Cleary (1993) and Browder and Godfrey (1997) than those found within household life-cycle theories or predominant political economy views of the frontier.

In discussions of capital accumulation in the Brazilian economy, and how Amazonia is articulated to it, one loses any sense of the Amazonian economy as a sphere of human agency, let alone social organization. It becomes a subsystem of a subsystem of a system. What defines it, the diversity and regional variation underlying social structure in Amazonia disappears. Hence the absence in classical frontier theory of much of what turned out to be important as the frontier evolved: the informal economy, towns and cities, and a multilayered emphatically non-monolithic state (Cleary 1993: 338).

The presence of contradictory processes within the frontier can only be understood as responses to these new opportunities emerging on the post-frontier. The growing urban peripheries, an expanding informal economy and the blurring of the urban-rural divide create new income earning opportunities. On the one hand, results show the ability of households to persist on the frontier and on the other, high levels of intraregional migration of household members suggest otherwise. The high survival rates of households on the frontier contrast sharply with the reduction of the overall population. While the main household keeps firm control over their original property, younger family members, *meeiros* and *agregados* move out into new emerging frontiers and urban peripheries. As the frontier progresses, this new context—the informal economy, processes of urbanization and socioeconomic differentiation of the emerging Amazonian population—challenge a simple allocation of family labor towards farm production. Once the household life cycle is complete, the new generation will find a more complex and dynamic setting than earlier generations encountered, one that will differentiate itself considerably from the life-cycle models and political economy frameworks researchers have used to explain the emergence of these frontiers.

CHAPTER 6

HOUSEHOLD LIFE CYCLES, LAND USE AND LAND COVER CHANGE IN THE BRAZILIAN AMAZON

Introduction

This chapter examines the role of household life-cycle factors in determining land use strategies among small landholders in the Amazon. It has been argued that the position of a household in its life cycle is a major factor shaping land use decision-making processes, and conversely, land cover change processes over time (Pichon 1996; Marquette 1998; Moran et al. 2003; Brondizio et al. 2002). The life cycle is, in turn, determined by the household's demographic composition, duration of residence on the lot, the number of years in the region and the age of the household head(s). Collectively, these variables locate the household in its normal life cycle. This chapter assesses the efficacy of the life cycle in explaining land use strategies at the farm level in relation to a range of other household level factors also identified as important in the literature (e.g., wealth, social capital, markets). The panel data set, spanning a ten-year period on the Amazonian frontier (1992–2002), presents a unique opportunity to determine the effect of household changes over time relative to corresponding changes in land use strategies.

Despite variants, the life-cycle theory emphasizes the importance over time of the relationship between changes in the household age structure and its impact on land use allocation. As households move through their life cycles, their socioeconomic and demographic characteristics, as well as their farming experiences will change. These changes will affect the degree of latitude that households have in making decisions. This chapter will examine these relationships and test whether land use allocation can in fact be explained by changes in position in the household life cycle. Its importance lies in the fact that different land use strategies and practices have different environmental and economic impacts. Knowing which factors can help promote the more sustainable land use practices can help in designing policies to curb current deforestation rates and guide a more sustainable landscape in the future.

This chapter is divided into five sections: the next section describes the different environmental and economic outcomes of different land use and land cover strategies and explains how they differ in their impacts; the third section outlines the methods used to analyze the relationships between household-level variables and land use outcomes including the purpose, hypotheses and the conceptualization and operationalization of different independent and dependent variables; the fourth discusses the results of multivariate regression analyses and the fifth expands into a discussion of findings, policy implications and conclusions.

Environmental and economic outcomes of land use and land cover change

Land use change processes can be linked to a range of different land cover types (i.e., annual crops, pasture, forest plantation), each of which can result in widely divergent short- and long-term environmental impacts (Browder 1994; Pichon 1997; Wood 2002). The conversion of primary forests to other land uses can have irreversible impacts on the ecological processes provided by the original forest, for example, loss of biodiversity and reduced carbon storage potential. However, these impacts will vary considerably in degree and intensity across the different possible land cover types. For example, logging will only remove a few trees per hectare, leaving the forest relatively intact, albeit with a lower value due to the selective removal of the more valued species and associated damages during harvesting⁵³. This contrasts with land cover classes that require the complete removal of all forest cover in order to establish agronomic crops or pasture, with subsequent higher impacts on nutrient and hydrological cycles. Furthermore, the degree to which a specific land cover class disturbs the original ecological functions can also vary considerably depending on the practices and intensity with which these practices disturb the site. For example, in the case of removing all the tropical forest, annual crops can be interspersed with native trees that can help maintain

⁵³ Conventional logging in the Amazon frontier is very selective, representing the extraction of only a handful of highly prized hardwoods, usually 4 to 8 trees per hectare from more than 300 to 400 trees. However, during a conventional timber extraction of this magnitude, up to 30 percent of the forest stand can be damaged (Biot et al. 1997) which means that 15–25 percent of its biomass is turned into dead debris (Summers 1998).

soil properties for longer periods than monocropping. Table 6.1 describes the different land cover classes in the region of Rondônia and their characteristics.

Table 6.1 Land cover classes and their characteristics

Land use type	Main Species	Advantages	Disadvantages
Annual crops	Beans (<i>Phaseolus comunis</i>), Rice (<i>Oryza sativa</i>), maize (<i>Zea mais</i>), manioc (<i>Manihot esculenta</i>), yams	Important for subsistence, Low labor maintenance, Produces in a year or less.	Poor market prices, Can only be produced for two to three years before land needs to fallow.
Perennial crops	Coffee (<i>Coffea arabica</i>), Cacao (<i>Theobroma cacao</i>)	Protect soil cover, Labor intensive leads to less deforestation.	Market crops require initial investments with returns only after 4 to 5 years, Labor intensive might discourage farmers with limited supply of labor, Price fluctuations.
Agroforestry plots	Peach palm (<i>Bactris gasipaes</i>), Cupuaçu (<i>Theobroma grandiflorum</i>), Timber species (e.g., <i>Swietenia macrophylla</i> , <i>Tectona grandis</i>)	Labor intensive leads to less deforestation, Higher biodiversity, Reduces economic risk by diversifying crops.	Labor intensive might discourage farmers with limited supply of labor, Poor market prices for many products.
Pasture	Brachiaria, Brachiarao	Low labor activities, Low risk activity, Increases value of land, Easy to establish after annual crops production.	Soil erosion and degradation, Soil compaction, Incompatible with most other land use classes, Requires frequent burning which can damage neighboring crops and forest.
Secondary fallows	Freijo (<i>Cordia sp.</i>), Bandarra (<i>Schizolobium panicum</i>)	Restores soil productivity, Wild game and non-timber forest products (NTFPs).	Low density of productive species, Simpler structure and composition than mature forests.
Primary Forest	Brazil nut (<i>Bertholletia excelsa</i>), Seringa (<i>Hevea brasiliensis</i>)	Wild game and NTFPs, Timber, Insecure tenure.	Low density of commercial species.

Pasture is believed to be the most damaging land use because of long term consequences for soil properties which can inhibit future forest regeneration (Uhl et al. 1988; Fearnside 1990; Saldarriaga and Uhl 1991). On the other hand, agroforestry systems and perennial crops are among the most favorable land cover types due to their

ability to fulfill some of the critical functions of the original forest (Smith et al. 1996). Annual crops can rapidly deplete available nutrients released during slash and burn activities, but, if interspersed with long fallowing periods, can also maintain critical soil properties and thus be potentially more sustainable than cattle ranching⁵⁴. However, the necessity to maintain large areas under different fallowing ages and the limited prospects of annual crops in the market makes it unattractive compared to other productive land uses. Other land cover practices include use of the forested landscape for non-timber and timber products. While most households initially rely on the natural resource capital available in the form of soil nutrients, biomass, timber, wildlife and other non-timber products, the medium to long term economic potential of timber and non-timber management systems among small landholders is limited because of the large areas required to expand into commercial scale (Browder 1992; Southgate 1998).

While land use and land cover practices all have differentiated impacts on the environmental sustainability of the site, there are also important inherent labor differentiations among land use strategies that are critical in land use decision processes. The labor-intensive nature of some land use practices such as perennial crops, contrasts markedly with the extensive nature of other practices such as cattle ranching. While a family that relies on its own labor can only sustain three to five hectares of coffee, the same family can look after more than one hundred hectares of pasture. Labor requirements linked to different land use classes have enormous implications for the amount of land a household is able to manage, the demand for clearing additional forest land and consequently for future deforestation rates. Recent increases in deforestation rates are linked to the increasing specialization of small landholders in the most destructive of land use practices, cattle ranching (Muchagata and Brown 2003; Kaimowitz et al. 2004).

The present chapter attempts to analyze the role of life-cycle variables across land use classes. For convenience, land use classes have been grouped into forest, secondary growth, annual crops, perennial crops and pasture. Most of the studies that look into household level variables have emphasized their role in deforestation but rarely in other

⁵⁴ However, see, Muchagata and Brown (2000) for a study of farmers' perceptions about soil fertility and their conviction that pasture systems are more ecologically stable than annual crops interspersed with fallowing.

land use classes (Godoy et al. 1997; Ozorio de Almeida and Campari 1995; Caldas et al. 2002; Walker et al. 2002). More recently, some studies have started to explore the role of life-cycle variables in the choice of specific land cover classes such as pasture (Caviglia-Harris 2004; Summers et al. 2002b) and secondary forests (Perz and Walker 2002). Other studies have attempted to study land cover classes as part of farming systems using cluster analysis (Walker et al. 2002; Browder et al. 2004) and multivariate regressions (Perz 2002). This study recognizes the need for a comprehensive analysis across land use classes and over time to improve our understanding of the role of the household life cycle in land use change.

This section has highlighted the need to move beyond deforestation models to study specific land cover classes and the household life-cycle factors that encourage or constrain the development of different farming systems. This is important due to the highly divergent environmental repercussions of different land cover classes. The fact that farmers already practice a diversity of land-use practices permits latitude in promoting more sustainable land cover practices and discouraging those that are detrimental to the environment or cause further migration to new deforestation fronts. Identification of the socioeconomic and demographic conditions promoting or inhibiting landholders in the adoption of certain combinations of land cover classes over others can become important planning tools for policy makers. Using the household life-cycle theory as the principal theoretical framework for understanding the links between household level factors and land use change requires a thorough review of its viability. These links have been extensively covered in the theoretical review section of chapter 2. The rest of the present chapter will test for the relevance of the household life-cycle theory in the post-frontier scenario of Rondônia and its impact on land use change.

Purpose and Research Questions

The purpose of this chapter is to test the role of household-level factors in determining land use and land cover change outcomes over time. I focus on the latter stages of the frontier stages as most of the original settlers are reaching the end of their life cycle. Additionally, I examine whether demographic and household-level factors

influence land use behavior and land cover outcomes as predicted in most household life-cycle models. Therefore, I pose the following questions:

- 1) Does the household life-cycle theory effectively contribute to understanding and predicting land use outcomes in the emerging post-frontier?
- 2) Can the different demographic and household-level factors that determine a household's position in its life cycle be used to explain changes in land use strategies and land cover outcomes over time? Can they be used to explain the differences in land use strategies and land cover outcomes between households?

Hypothesis

The overall hypothesis for this chapter is as follows:

HO: Land use and land cover change outcomes at the lot level are determined by the changing demographic structure of the property owners' household life cycle.

The discussion of how key land use outcomes shift in importance and extension as a household proceeds through its life cycle have been extensively reviewed in chapter 2. Based on figure 2.1 which describes land cover change outcomes at different stages of the household life cycle, I hypothesize the following;

H1: As a household reaches the end of its life cycle **and** out-migration of young adults occurs as they leave to establish their own farms or to find employment in the growing urban areas of the region, labor availability on the farm will be hampered by the increasing ratio of dependents to adult laborers. This leads to a reduction of the land area under crops and pasture (annuals will decrease immediately while perennials might hold for some years), an increase in the amount of secondary growth, and a decline in the

deforestation rates in the lot. **Independent variables:** age of household head, number of working-age household members, dependency ratio and duration of residence on the lot

An alternative scenario is possible where grown children stay in the household. This represents a generational shift as the older generation passes control of the farm to the next generation with very different land use change consequences.

H2. As a household reaches the end of its life cycle **and** grown children take over the management of the farm, the number of working-age household members will increase and the dependency ratio will remain low. Additional demand for land will lead to clearing primary and secondary growth forest to renew crop cultivation, expanding the area under annual and perennial crops and pasture formation as young children expand subsistence demand. **Independent variables:** age of the household head, number of working-age household members, dependency ratio and duration of residence on the lot.

The results of the household life cycle are not straightforward and the interaction with other theoretically important variables has to be considered in determining their impact on land cover classes. Additional hypotheses are specified under the description of the different independent variables considered to link them to the hypothesized interaction with the household life cycle.

Methodology: Dependent and independent variables

To fulfill the data quality requirements of multivariate analysis, all dependent and independent variables are subject to the following pre-analysis data screening procedures and transformations (Mertler and Vannatta 2001: 25–66):

- (1) Frequency tables – If more than 15 percent of the cases of a variable are found missing, the variable is deleted from the analysis.
- (2) Box-plot analysis – Unusual or extreme values (outliers that have z-scores greater than +3.00 or less than -3.00) are replaced by the highest or lowest acceptable value.
- (3) Univariate normality – Normality tests (Kolmogorov Smirnov statistic) and skewness and kurtosis coefficients were estimated to determine if a given variable

is normally distributed. Variables that were not normally distributed were transformed following the procedures in Mertler and Vannatta (2001: 30–32) and summarized in appendix B.

Three different data samples are used in this study:

- (1) 1992 sample; refers to households interviewed in 1992
- (2) 2002 sample; refers to households interviewed in 2002
- (3) Survivors panel sample; households interviewed in 1992 and who were still in the same lots in 2002

Since the unit of analysis for this study is the household and not the plot, the survivor panel sample includes those households that were interviewed in both years, eliminating from the analysis any new households in the sample frame of 2002.

Outcome or dependent variables

Small landholders engage in a diversity of complementary land use strategies that result in different land cover classes and consequently different environmental and economic outcomes. For comparative purposes I consider five land cover classes that are traditionally used in the literature as the outcome or dependent variables: annual crops, perennial crops, pasture, secondary growth and forest. An explanation of the potential ecological and economic consequences of the different land use classes was discussed in the previous section and how these consequences may vary in importance according to the life-cycle stage was reviewed in chapter 2.

All land cover classes are expressed in hectares and have been transformed into a normal distribution if the original scores were not normally distributed following the transformation procedures in appendix B.

Table 6.2 presents outcome or dependent variable names, their operational definition and their descriptive statistics.

Table 6.2 Variable names, operational definitions, mean and standard deviation of land use variables (outcome or dependent variables) for the three subsamples tested.

Variable	Operational definition	1992	2002	Change (1992–2002)
Secondary growth	Hectares of secondary growth	5.8 ± 7.0	6.0 ± 8.3	1.5 ± 10.5
Annual crops	Hectares of annual crops	5.2 ± 4.5	2.6 ± 2.9	-2.5 ± 5.1
Perennial crops	Hectares of perennial crops	7.0 ± 7.3	9.1 ± 8.9	2.4 ± 9.2
Pasture	Hectares of pasture	19.1 ± 30.4	47.6 ± 59.4	29.8 ± 37.9
Forest	Hectares of remnant primary forest	42.1 ± 25.0	29.5 ± 25.7	-9.3 ± 22.8

Independent variables

Household life-cycle variables were introduced in chapter 3 and have been tested in chapter 4 to see if they could explain changes in the size and ownership of properties. In this chapter I test household life-cycle indicators against other possible explanatory factors in explaining changes in land use and land cover. Explanatory factors are classified into one of eight different groups according to the literature (Ellis 2000; Wood 2002). These groups include: life-cycle position, socioeconomic background, demographic characteristics, human capital, social capital, wealth (assets), market integration and lot context. Classifying explanatory variables into groups allows comparing the relevance of life-cycle variables with other types of variables that have been theoretically linked to land use change (Godoy et al. 1997; Perz 2002). Descriptive statistics, operational definitions and correlations between the explanatory and the dependent variables (land cover types) for each of the two years surveyed (1992 and 2002) and for the difference between the two study years (1992–2002) are presented in appendix C. Correlations between explanatory factors and land use classes cannot yet be said to correspond to a theoretical cause-effect relationship; the possibility of this relationship is merely suggested. The theoretical links will be examined and tested in the next section using multivariate regression models. The following discussion further defines and operationalizes these proposed explanatory variables.

Household life-cycle location

The household life-cycle theory posits that the key factor in land use decisions is the location or position of the household in its domestic life cycle (Marquette 1998; McCracken et al. 1999; Perz 2002; Walker and Perz 2002). I consider four indicators of the household life-cycle position: *duration of residence*, *age of household head*, *dependency ratio* (ratio of dependents to adult household labor) and the *number of adult workers*.

The first variable, *duration of residence on the lot* indicates the labor time the household has invested in making the lot productive. For households that possess more than one lot I consider the number of years in residence on the longest-owned lot. Longer ownership duration should correspond to improvements in land use practices as the household experiments and adapts towards more appropriate farming techniques (Moran 1989). Longer duration of lot residence should also correspond to less forest and increases in the other land cover classes, especially perennial cash crops and pasture.

Households presented a mean residence of 16 years on the lot (2002 survey) with a considerable variation among farmers (standard deviation = ± 8 years). Due to a moderately negatively skewed distribution, the original values were transformed into a normal distribution by subtracting them from a constant value of 30 and calculating the square root of these values (see appendix B). Significant positive correlations were found in the 2002 survey between these values and secondary growth but not for other land cover classes (Table C.2). For changes in the different land cover classes during the last ten years, the *duration of residence* correlates with a considerable decrease in the areas of perennial crops and, of course, in the area allocated to forest (Table C.3).

The second life-cycle variable, *age of household head* is an indicator of the time the household has been working in a given economically productive activity. Unlike *duration of residence*, this variable estimates another kind of knowledge which comes with age but which is not necessarily linked to experience acquired in the region. Therefore, this variable can be independent of the *duration of residence* since households with similar time of residence can have household heads of different ages. An example

can be a young couple arriving from outside the region compared to those who have arrived from other Amazonian frontier regions or from those who have previously been sharecroppers in nearby lots. Therefore, older households can be more experienced with markets and cash crops and not just with working on the land. I expect that household age will correlate with increasing expansion of productive activities, especially longer-term perennial cash crops, and at the end of the life cycle an increase in secondary growth as sons leave the farm for land of their own. The mean age of the household head in 2002 is 52.2 ± 12.7 and correlations were significant and positive between age and the area under secondary growth and perennial crops (Table C.2). When correlations were tested for changes in land use areas during the study period (1992–2002), the household head's age was found to be negatively correlated with the expansion of pasture (Table C.3).

The third life-cycle variable, dependency ratio (children under 16 years of age and adults over 65 years of age over all other household members), is an indicator of the household's adult labor force in relation to the number of dependents in the household. Higher dependency ratios are associated with the initial stages of the life cycle, characterized by a higher proportion of children in relation to adult family labor. Therefore, households with higher dependency are theoretically linked to the production of annual crops (e.g., rice, beans, banana, maize). As children grow and become young working adults the dependency ratio diminishes. Lower dependency ratios are associated with a greater abundance of labor in relation to family dependents permitting the allocation of land use to labor-demanding cash crops such as coffee and cacao. In the empty nester scenario, as children migrate out of the farm and the household head reaches maturity the dependency ratio should increase once again.

Diverging from the expected, the mean change in the dependency ratio (1992–2002) was -0.385 for all households and -0.202 for the main household (F1). The lower ratio of dependents/adults in 2002 in relation to 1992 is probably due to a combination of factors; young adults are not leaving the household, the new generation of young families is having fewer children than their parents did, and grandparents and elderly people are moving to urban centers where they have easier access to medical services. Furthermore, correlations were non-significant for dependency ratios and land cover classes for the two survey years (Tables C.1 and C.2) and for the change between the two years (Table C.3).

The fourth life-cycle variable, *adult household labor (F1)* indicates the amount of household labor available to the main household unit, independent of overall family size. Correlations with land cover classes found a significant positive relationship in 1992 between *adult household labor* and the extent of perennial crops, annual crops and interestingly, forest. However, these relationships are absent in 2002 in the case of perennials and forest but still significant in the case of annual crops. Overall, no correlations are found between changes in the expanse of the different land use classes and the change in the availability of household adult labor between the two survey years.

The interaction of this group of variables, classified as life-cycle variables, which is central to the household life-cycle theory, are compared with other groups of variables also identified as theoretically important in the literature using multivariate regression models. The following section examines other demographic variables that are not considered life-cycle indicators.

Other demographic variables

To account for changes in the inner structure of the household that are not important for locating the household along its life cycle, other demographic variables are included in this section. These could be important in explaining differences between households located in the same life-cycle stage. The existence of other families, such as *meeiros* or *agregados* (sharecroppers) and hired workers who also live on the lot can potentially relax the labor constraints of the main household presented in the life-cycle theory.

H3. As households reach the latter stages of their life cycle, those that have a larger number of families and sharecroppers living on their lot will be able to expand the areas in production (annual crops, perennial crops and pasture) and consequently reduce the area allocated to secondary growth and forest. **Independent variables:** *number of families*, number of *agregados* (sharecroppers), *agregados* (yes/no).

The *number of sharecroppers* fell from a mean 1.2 ± 2.67 in 1992 to 0.53 ± 1.18 in 2002. Two interpretations of these findings are feasible. First, as expected, this variable correlates positively with the area planted in both perennial crops and pasture. Not surprisingly, households are more likely to hire non-family workers if their farming systems are heavily oriented to commercial cash crops (e.g., perennials, cattle) regardless of their particular stage in the household life cycle. Second, there was a reduction in the number of non-family workers during the study period during a time when family members are presumably leaving the household and the farming system is shifting to more commercial cash crops. This seems curious, and not consistent with the empty nester scenario of the household life-cycle theory. The finding seems to support the prevalence of a generational shift scenario as the households reach the latter stages of their life cycle.

Similarly, the *number of families* on the lot fell from a mean 1.74 ± 1.05 in 1992 to 1.48 ± 1.05 in 2002, and while this correlates positively with both annual and perennial crops in 1992 it only does so for perennial crops in 2002. However, the change in the *number of families* between the two survey years positively correlates with the change in the areas of both perennial and annual crops (Table C.3) suggesting an important relation between the number of families and productive activities in the lot.

Gender ratios within the household also could account for differences in land use as suggested in gender studies (Overholt et al. 1991; McDougall 2001; Porro and Stone 2005). Although the influence of women on land use has been acknowledged, household life-cycle research has rarely taken women or their contribution into account⁵⁵. For example, it is known that women are more inclined to invest additional income in health and education than male household heads, therefore a female household head or a stronger ratio of adult women in the household demographic structure could lead to the planting of agricultural products more important for the household's subsistence. The presence of women could explain the maintenance of annual crops over time despite the hypothesized shift toward less labor intensive land uses (e.g., pasture) predicted for the latter stages of the life-cycle theory.

⁵⁵ A notable exception is a recent study focused on migration in the Ecuadorian Amazon exploring differences between men and women migrants. Although it has important land use implications it does not test for the impacts these might have over land use.

H4. As households reach the later stages of their life cycle, a stronger presence of adult women is associated with a larger proportion of land allocated to annual and perennial crops. **Independent variable:** Number of adult women (F1) and number of adult women (All).

The mean number of women in the main household in 1992 was 1.43 ± 0.85 and, as expected, positively correlates with a larger proportion of annual and perennial crops as well as with the remaining forest area (Table C.1). By 2002 the mean number of women in the main household falls to 1.33 ± 0.84 and is positively correlated with annual and perennial crop land use classes but no longer with forest land cover class (Table C.2). However, the change in the number of women during the study period (1992–2002) was not correlated with any changes in land cover classes.

Socioeconomic background

The socioeconomic background of the household refers to the initial cultural and financial capital that the household possesses on arrival at the frontier. Such characteristics have been associated with the resilience or survival capacity of the household (Moran 1989; Ozorio de Almeida 1992). I include two measures of the initial conditions of the household in the frontier; (1) the region of birth of the household's head, and (2) a factor-weighted index of the household's initial capital when arriving in the frontier⁵⁶.

The household head's birth region has been identified as a surrogate indicator of his cultural capital (Ellis 2000; Perz and Walker 2002). It has been argued that households arriving from the more industrialized southeastern states of Brazil will be more familiar with technological innovations in agriculture to adapt to market-based cash

⁵⁶ The wealth index was constructed using a list of indicators of the level of the household's accumulated wealth. Different items were assigned different weights depending on their relative importance. Weighted index = gas stove (x2) + refrigerator (x1) + television (x1) + antenna (x2) + car (x3) + house in the city (x2) + chain saw (x3) + tractor (x3) + truck (x2) + motorcycle (x2).

crops than their counterparts from the poorer states of the Center-West and Northeast⁵⁷ (Moran 1989; Ozorio de Almeida and Campari 1995). Ozorio de Almeida and Campari (1995) in fact found significant differences in the survival rates of Southeastern-raised household heads when compared to migrants from the Northeast for colonization programs in Mato Grosso and southern Para. Southeastern migrants also arrived on the frontier with better financial and capital assets than those that arrived from the Northeast⁵⁸.

H5. As households reach the end of their life cycle, those households that initially arrived to the frontier with a comparative advantage, cultural (e.g., from regions that enjoyed higher levels of education) or financial (higher initial wealth assets), will have been able to further expand their productive area leading to larger areas allocated to pasture, perennial crops and annual crops and less forest and secondary growth. **Independent variables:** Cultural background and initial wealth index.

Coming from the South or Southeast and arriving at the frontier with more capital should increase land use options, perhaps leading to a more intensive use of the lot, especially the expansion of perennial crops. However, correlation coefficients between households arriving from the South and Southeast and the different land use classes were not significantly higher than those arriving from the north and northeastern and central-western states (Tables C.1 and C.2).

A number of studies have found initial assets (wealth) to have statistical significance in determining the resilience and area under production of the household on the frontier (Ozorio de Almeida and Campari 1995). Data from the 2002 subsample

⁵⁷ I used the classification in Ozorio de Almeida and Campari (1995). Southern migrants come from Sao Paulo, Santa Catarina, Rio Grande do Sul and Parana and the Center-West and Northeast include all other states, specifically Espiritu Santo, Bahia, Para, Mato Grosso, Goiais and all the traditional Northeastern states such as Maranhon, Ceara, Paraiba, Alagoas, etc.

⁵⁸ Martine described the Southeastern migrants arriving at the Rondônian frontier as being quite distinct from the Northeastern migrants that colonized the frontier regions in the North and Central West frontier of northern Mato Grosso. "Many of the settlers were experienced farmers and most of them had been pioneers in other colonization efforts in the states of Parana and Mato Grosso. Many of these would-be-settlers brought with them capital derived from the sale of their lands, along with machinery, animals and household goods (1981: 90)."

showed a significant positive correlation with the area of the lot in pasture but not for the other land cover classes (table C.2).

Human capital

Human capital refers to the knowledge base of the household (Ellis 2000; Perz 2004). It considers not only the knowledge that is acquired through formal education, but, particularly in agricultural frontier regions, that which is acquired through practical learning and experience⁵⁹. Therefore, I include two different indicators of a household's human capital; (1) the number of years of schooling the household head(s) has completed, and (2) how long the household head has resided in the region. Human capital is not directly related to the household life-cycle theory but is theoretically linked to land use changes. It is tested for comparative purposes along with demographic and life-cycle indicators.

Theoretically, higher formal education levels should give a comparative advantage for farmers as they enter into market-based relationships (Godoy 1998; Ellis 2000). In an increasingly market-oriented context it would be expected that higher levels of education would favor better economic transactions and therefore higher levels of agricultural capitalization. However, the effects of agricultural capitalization among rural landholders on land use practices are still a matter of debate (Godoy 1998; Angelsen and Kaimowitz 2001; Perz 2004).

The second variable, *years in Rondônia* is an indicator of the amount of local agricultural knowledge that the household has acquired through experimentation and experience. In theory, as households experiment with different land use practices, agricultural techniques and agricultural crops, the household accumulates knowledge about what farming strategies work best and this has a positive impact on land use practices over time (Moran 1989). It differs from *age of household head* and *years on lot* by specifically addressing the time spent in the region, and therefore knowledge

⁵⁹ It also includes a household's health and ability to work but we do not have the information to include these as part of the operationalization of human capital.

acquisition that is not necessarily linked to just farming experience, but also to human capital formation from living in the Amazon region.

H6. Households that have higher levels of human capital, specifically higher levels of formal education (years of schooling) and informal education or local knowledge (years in Rondônia) will promote more intensive land use practices, specifically larger areas allocated to perennial crops, and preserve larger areas of forest. **Independent variable:** *years of schooling* and *years in Rondônia*.

Table C.2 shows no significant correlations between human capital indicators and land use classes in 2002. When considering a change in the extension of land use classes during the study period (1992–2002), a negative correlation is found between the human capital indicator *years in Rondônia* and the extension of perennial crops planted (Table C.3). Assuming that perennial crops are ecologically more beneficial than most of the other land use classes, I would have expected a positive correlation between perennial crops and human capital indicators. Other factors seem to be overriding the benefits of accumulated knowledge of the household. The end of the life cycle, characterized by reduction of soil fertility of most areas under production and a decrease of interest in crops demanding intensive manual labor (perennial crops) could be overriding the decision to invest in perennial crops.

Participation in Social Organizations (Social Capital)

Social capital refers to social resources such as social networks and membership in associations and other forms of civil society groups that facilitate collective action for mutual benefit, access to wider institutions in society and, if possible, affect the way in which the market and the state operate (Evans 1996; 1997; Woolcock 1998)⁶⁰. Examples

⁶⁰ Social capital encompasses a myriad of definitions and conceptualizations, and the mechanisms to measure it are not fully developed. There are two major conceptualizations that I identify in the literature. The first associates social capital directly with beliefs and behavioral dispositions, such as norms of cooperation, goodwill and trust (Fukuyama 2001). A second group of writers claims trust and cooperation are the result of social capital, and that measurable variables should be identified that create these conditions in a community (Narayan and Pritchett 1999; Torsvik 2000). I tend to fall into the second group.

of indicators of social capital range from mutual aid groups among neighbors (e.g., to buffer crop failures and assist in harvests of perishable crops) to cooperatives that can help secure better prices for agricultural products.

It has also been argued that social organizations serve as efficient ways of disseminating sustainable land use practices (Caviglia-Harris 1998; Browder and Pedlowski 2000). Farmers that engage in social organizations are more exposed to learning other farming techniques and can form associations and cooperatives to market products that otherwise could not be able to compete, including ecologically-friendly agricultural products. While the participation in different social organizations does not guarantee better farming practices, it allows more latitude to practice more intensive forms of agriculture than otherwise.

Three types of social organizations are used as indicators of a household's social capital; labor sharing, economic and political organizations. The labor sharing type of organizations are locally called mutual help associations and can be defined as informally based neighborhood organizations that serve as labor sharing mechanisms during harvesting and other labor-demanding periods⁶¹. Economic types of social organizations are represented by cooperatives. These are market-based organizations of smallholder producers to secure higher prices for agricultural products. Finally, the political dimension of social organizations is represented by households' participation in labor syndicates. Participation in syndicates such as the MST (Movimento Sem Terra) help leverage the capacity of small landholders to negotiate for their interests in local politics.

H7. Households that are involved in social organizations will be able to expand their agricultural crops, specifically annual and perennial crops, and reduce the area allocated to pasture and secondary growth. **Independent variables:** Participation in mutual help associations, participation in cooperatives and participation in syndicates.

However, like most authors who attempt to measure social capital, I infer its existence indirectly measuring the participation of households in collective action groups and organizations (e.g., Putnam 1993; Bebbington 1997; 1999; Narayan and Pritchett 1999).

⁶¹ Mutual help associations usually emerge as informal ways of pooling a large labor supply when capital is scarce. Thus it is usually more common during the opening of the frontier, after households have invested most of their saving in moving and adult labor within the family is scarce.

Table C.2 shows that 49 percent of the panelized households in 2002 participated in mutual help associations, 60 percent were affiliated with a syndicate and only 9 percent had joined a cooperative. Interestingly, significant positive correlations were found between households participating in associations and syndicates and the area allocated to annual and perennial crops. This correlation was not found in the case of cooperatives probably owing to the small number of households that participate in this type of organization. Table C.3 shows that the positive correlations between households participating in social organizations and the area planted in annual and perennial crops hold when considering changes in the area planted between the two survey years. How these compare and interact with life-cycle indicators for explaining land use will be tested through multivariate regression models.

Wealth (Assets)

Wealth refers to assets a household has been able to accumulate over time. It has been argued that among small landholders, wealth is a better indicator of household wellbeing than income, which can vary considerably from year to year (Barham et al. 1999; Ellis 2000; Takasaki et al. 2001)⁶².

The relationship between wealth and land use is still highly debated. One argument holds that households able to accumulate wealth are more prone to intensify production and might be more capable of investing in conservation practices, both of which could lead to reducing deforestation (e.g., Serrão and Homma 1993; Godoy 1997; Vosti et al. 2002). Another line of reasoning is that additional wealth will give households more latitude to invest in land and correspondingly allocate more forest to other classes of land use (Perz 2002; Walker et al. 2002).

⁶² Barham et al. (1999) note that wealth holdings affect economic choices related to making a living in the frontier in several ways; they provide households with (1) the material basis for producing subsistence goods and cash income (e.g., chainsaws to clear forests), (2) a buffer against bad times, either as a form of insurance to smooth consumption or to enable income diversification, and (3) the basis for higher permanent consumption (e.g., the purchase of a generator to provide electricity). Wealth also affects livelihood strategies in more indirect ways. In the absence of markets for credit, households with greater assets are more able to self-finance investments in forest extraction and other activities. Furthermore, when and where credit is available, wealth can be used as collateral for loans allowing households to expand into alternative economic activities. Finally, wealth gives a household self-insurance in the risky frontier environment, enabling them to engage in more profitable but riskier land use strategies.

Following a household life-cycle approach I would expect a differentiated impact. During the initial phases of the household life cycle, wealth should relax capital constraints and allow the household to open land for other uses further increasing deforestation rates. On the other hand, during the late phases of the life cycle, a household will be further constrained by diminishing soil fertility, for which additional resources would be needed to intensify production, investing in fertilizers and pesticides to maintain production levels and possibly adopting soil conservation methods for the same reason. This follows Boserup's thesis that land intensification processes will only occur in the case of increasing population and environmental constraints (Boserup 1965; Netting 1993; Angelsen and Kaimowitz 2001).

I use four indicators of wealth in this study; *cattle herd size*, *ownership of multiple rural lots*, *ownership of urban properties* and a wealth index that is a weighted sum made up of a list of consumer durable goods that a household possesses. Cattle have been traditionally linked to the accumulation of wealth in the developing world, and most farmers, when possible, will invest their earnings in increasing their cattle herds (Hecht 1993; Pichon 1997). The other common form of investing capital earnings in the frontier is the acquisition of additional land. A more recent trend is the purchase of urban properties⁶³.

H8. In the earlier stages of the household life cycle, in our case the 1992 subsample, wealth indicators will be associated with larger areas of perennial crops and pasture and fewer hectares allocated to annual crops and secondary growth. As a household reaches the latter stages of its life cycle, in our case in the 2002 subsample, wealthier households will be able to further invest in more appropriate land use practices such as perennial crops and reduce the area allocated to pasture. **Independent variables:** cattle herd size (of owned, not boarded cattle), ownership of multiple rural lots, ownership of urban properties and wealth index.

⁶³ Having a foothold in the city is often advantageous, allowing part of the household to migrate to the burgeoning cities of the frontier where they can take jobs outside of the agricultural sector, reducing the risk of depending solely on agricultural production. Furthermore, they can get their children into middle school, secure better prices for rural products, or reduce costs incurred by illness and smooth consumption patterns if necessary when rural products do not have good prices.

Table C.1 shows that, as expected, in 1992, wealth indicators were negatively associated with the production of annual crops and positively correlated with the expansion of pasture. Following our preceding observations on the relation between household life cycle, wealth and land use, I would expect that by 2002, wealth would correlate with more intensive land use classes, specifically an increase in perennial crops and the reduction of secondary growth. However, table C.2 shows that wealth indicators were negatively correlated with perennial and secondary growth land cover classes and positively correlated with pasture expansion and curiously the maintenance of forest area. A larger proportion of forest area for wealthier households is probably linked to the expansion of landholdings as these households aggregate new lands many of which still hold considerable amounts of forest.

Market integration

Market integration refers to the level of household participation in the market economy⁶⁴. The level of market integration, in turn, affects land use change by encouraging the expansion of production beyond subsistence, and specialization towards marketable cash products (e.g., coffee, cattle). The capacity of households to rely on markets for their livelihood, in turn, is affected by the economic integration of the frontier region into the rest of the economy on one hand, and on the other, by the household's own life cycle and demographic characteristics that can constrain its ability to produce market products competitively, specifically in the early and late stages of its life cycle in the case of an empty nester scenario.

As the frontier moves through each successive phase, the gradual integration of the region into the rest of the national economy permits the reduction of production and transaction costs, improving the conditions of small landholders to shift from subsistence to market production. However, not all households have the capacity to rely solely on

⁶⁴ Although most small landholder farmers in the Amazon operate within the market context, labor, capital and food market failures are pervasive features of agricultural frontiers. A market failure occurs when the cost of a transaction through market exchange creates a disutility greater than the utility gain produced, with the end result that the market is not used for the transaction (De Janvry et al. 1991). Therefore, while markets exist in agricultural frontiers, the gains for a particular household may be below or above cost, with the result that some households will use the market while others will not.

markets to fulfill their livelihood needs, employing instead a mix of informal economic arrangements and market transactions that vary from household to household and within households over time (Ellis 2000). Other studies in the region have suggested that the frontier is differentially articulated to the rest of the national economy (Browder and Godfrey 1997), therefore the level of market integration among rural households is still noticeably variable, presumably influencing economic strategies and therefore land use decisions.

I use five different variables to measure the level of integration of the household into the market: *off-farm income*, *hired workers*, the *percentage of farm production marketed* (versus consumed on-farm), *access to credit* and the use of a *savings or checking account*. Off-farm income is a binary variable that indicates whether the household has or does not have family members engaged in off-farm economic activities. Similarly, hired workers is a binary variable that specifies if the household paid or did not pay *diaristas* or non-family members to engage in different farm related activities. The third variable, *percentage of farm production marketed*, is the proportion of total farm production (output) that was actually sold⁶⁵. Access to credit and the use of a savings or checking account are both binary variables.

H9. Households that are more integrated into the market will have larger areas allocated to the production of cash crops, especially perennial crops, and the reduction of the area allocated to annual crops and secondary growth. **Independent variables:** off-farm income, hired-workers, percentage of farm production marketed, access to credit and savings or checking account.

Table C.1 shows that, in 1992, 20 percent of households received off-farm income and 42 percent hired temporary and daily workers. However *off-farm income* does not correlate with any land use class, while the hiring of temporary workers correlates

⁶⁵ The percentage of farm production marketed was obtained by converting all production figures into their monetary value using the actual value sold. Consumption was converted into its equivalent sale value by shadow pricing production consumed with the mean market price of the product. The percentage was estimated using the proportion of the sum of annual crops, perennial crops and extracted forest products divided by the sum of the total monetary equivalent of the agricultural and forest extraction products sold and consumed.

positively with annual crops and, surprisingly, with pasture. The third variable, *percentage of production sold* shows that farmers sold a mean 57.4 (± 29.7) percent of their production and this is positively associated with the extension of perennial crops. By 2002 the percentage of households engaged in off-farm income generating activities had increased to 59 percent, the percentage of households that paid *diarias* to 57 percent and the *percentage of farm production sold* increased to 70.5 ± 35.2 (Table C.2). Table C.3 shows the correlations between market integration variables and changes in the area of the different land use classes for the study period 1992–2002. No strong correlations between market integration variables and expected land use classes were found.

Lot Context

Lot context refers to variables that are exogenous to the socioeconomic and demographic characteristics of the household but have been identified in the literature as significantly affecting the household land use decision-making processes. Among these factors I identify distance to markets, incidence of fires, availability of surface water, soil type, topography, size and other biophysical and contextual features of the lot. I test the first two factors, distance to markets and incidence of fire, as well as lot area since they were easily available from the surveys⁶⁶.

One of the most frequently mentioned factors claimed to affect deforestation levels among lots is distance from major market centers. Von Thunian models of land use change identify transportation costs as the single most important variable explaining land use change processes (Chomitz et al. 1996; Mertens et al 2004).

H10. Regardless of the position of the household in its life cycle, the distance of the lot to the nearest market center is negatively correlated to the area allocated to marketable crops, specifically the area in annual and perennial crops, and positively correlated to the amount of secondary growth and primary forest standing. Since pasture is an extensive land use strategy I hypothesize the area allocated to pasture will be negatively associated

⁶⁶ A preliminary run was employed for availability of water for one of the study sites (Alto Paraiso), but no correlation was found between this variable and land use change processes.

with the distance to market centers. **Independent variable:** distance to nearest market center.

Similarly, recent literature that studies the influence of fire on the Amazonian region has suggested that accidental fires could negatively affect incentives to plant perennial and agroforestry plots (Nepstad et al. 1999). The incidence of fires on lots during the study period (1992–2002) is measured as a binary variable.

H11. The incidence of fires on a household's plot is negatively associated with the extension of perennial crops planted. **Independent variable:** Incidence of fire on the lot.

Table C.2 shows that for 2002 values, as hypothesized, the distance to markets was negatively correlated to annual crops and positively correlated to the amount of primary forest left in the lot. However, in the case of explaining land use change between the two study years, distance to market correlates positively only to the expansion of pasture. In the case of incidence of fire, the presence of accidental fires on the lot does not correlate with any changes in the allocation of different land cover classes.

The regression models

The theoretical model used in this study describes the relationship between the household life cycle and land use and land cover change. The output or dependent variables are the five major land cover classes described above; annual crops, perennial crops, pasture, secondary growth and primary forest. The independent variables consider five groups of several indicator variables that are hypothesized to affect land use and land cover change outcomes. These groups include the household life-cycle indicators [hhlc], which represents the most important group tested, and other groups of theoretically important variables that I have grouped into the following classes; lot context [lotct], social participation [socpart], wealth [wth] and market integration [mrk]. Other variables were tested but discarded mostly for one of two reasons; (1) they had proven to have low correlation values with the different land cover classes in the correlations examined

above, or (2) they were found to have high collinearity values with other predictor variables. When two independent variables were found to have high collinearity, since two highly correlated independent variables cannot be in the same regression model, one had to be discarded from the analysis.

Three different groups of multivariate regression models were considered, representing each of the three different subsamples identified; (1) 1992 subsample [92], (2) 2002 subsample [02], and (3) the change or difference between both years, subtracting 1992 values from 2002 values [92-02].

The three groups of regression equations have five different output or dependent variables representing the five land cover outcomes described above (columns), and the five groups of independent variables (rows), with some variation of the variables within each group that will be explained below. Therefore, using the conventional multiple regression model equation:

$$\square = B_0 + B_1X_1 + \dots + B_kX_k + A$$

Where \square is the predicted value for the dependent variable

B_0 = regression coefficient for constant

B_1 = regression coefficient for each one of the independent variables

X = raw scores for each independent variables

A = errors of prediction or residuals

Regression models are specified as follows:

- (1) (Land cover class)₉₂ = $B_{92[\text{hhlc}]}$ $X_{92[\text{hhlc}]}$ + $B_{92[\text{lotct}]}$ $X_{92[\text{lotct}]}$ + $B_{92[\text{socpart}]}$ $X_{92[\text{socpart}]}$ + $B_{92[\text{wth}]}$ $X_{92[\text{wth}]}$ + $B_{92[\text{mrk}]}$ $X_{92[\text{mrk}]}$ + A
- (2) (Land cover class)₀₂ = $B_{02[\text{hhlc}]}$ $X_{02[\text{hhlc}]}$ + $B_{02[\text{lotct}]}$ $X_{02[\text{lotct}]}$ + $B_{02[\text{socpart}]}$ $X_{02[\text{socpart}]}$ + $B_{02[\text{wth}]}$ $X_{02[\text{wth}]}$ + $B_{02[\text{mrk}]}$ $X_{02[\text{mrk}]}$ + A
- (3) (Land cover class)₉₂₋₀₂ = $B_{92[\text{hhlc}]}$ $X_{92[\text{hhlc}]}$ + $B_{92[\text{lotct}]}$ $X_{92[\text{lotct}]}$ + $B_{92[\text{socpart}]}$ $X_{92[\text{socpart}]}$ + $B_{92[\text{wth}]}$ $X_{92[\text{wth}]}$ + $B_{92[\text{mrk}]}$ $X_{92[\text{mrk}]}$ + A

$$(4) \quad (\text{Land cover class})_{92-02} = B_{92-02[\text{hhlc}]} X_{92-02[\text{hhlc}]} + B_{92-02[\text{lotct}]} X_{92-02[\text{lotct}]} + B_{92-02[\text{socpart}]} X_{92-02[\text{socpart}]} + B_{92-02[\text{wth}]} X_{92-02[\text{wth}]} + B_{92-02[\text{mrk}]} X_{92-02[\text{mrk}]} + A$$

$$(5) \quad (\text{Land cover class})_{92-02} = B_{92-02[\text{hhlc}]} X_{92-02[\text{hhlc}]} + B_{92-02[\text{lotct}]} X_{92-02[\text{lotct}]} + B_{92-02[\text{socpart}]} X_{92-02[\text{socpart}]} + B_{92-02[\text{wth}]} X_{92-02[\text{wth}]} + B_{92-02[\text{mrk}]} X_{92-02[\text{mrk}]} + A$$

[hhlc] = household life-cycle indicators
 [lotct] = lot context indicators
 [socpart] = social participation indicators
 [wth] = wealth indicators
 [mrk] = market integration indicators

Furthermore, for each dependent variable two different set of columns are shown; the first tests for household life-cycle variables considering only the main household (F1) and the second column tests for household life-cycle variables considering all households living in the lot (ALL), including extended families, and sharecroppers.

Results

The power of the household life-cycle theory lies in its simple yet dynamic ability to specify land use outcomes as a function of the life-cycle stage that a household is located at. This chapter attempts to test if in fact the household life cycle can determine the different land use outcomes that are found at the property level. Land-cover types have been classified into five groups whose extent can be derived from the household life-cycle model. These are annual crops, perennial crops, pasture, secondary growth and forest. On the other side, independent variables include household life-cycle indicators and other variable types which household life-cycle indicators are tested against.

This section presents the results of multivariate regression land use models for the two study years, 1992 and 2002, and for the difference between both years. While the previous section examined correlation values between potential predictor variables and the different land cover classes, multivariate models can only include a limited number of these variables due to constraints of the sample size. The variables were selected out of all the potential variables introduced in the correlation matrixes and later tested into the models. Variables were chosen because they were theoretically important and proved to

be statistically significant for at least one or two outcome variables. Furthermore, I used the same set of variables for all outcomes to facilitate comparisons among the models. In this way I tried to develop a single set of variables that represented a stronger model overall. In the end, two sets of variables are included in order to compare household life-cycle indicators using all families in a household (including *agregados* and *meeiros*) and another just with the main household (F1).

Multivariate regression model results are presented in tables D.1 and D.2 for 1992 and 2002 respectively and in tables D.3, D.4 and D.5 for the difference between 2002 and 1992 values. As explained above, regressions for each dependent variable were run using two different sets of demographic life-cycle variables. The first model, represented by the first column under each outcome variable, uses demographic variables derived from the main family household only, designated F1. The second column tests life-cycle variables that aggregate the sum of all the families on the lot (the percentage of households with multiple families was 45.2 percent in 1992 and 38.6 percent in 2002). By first using only the main household unit (F1), the demographic structure of the household could be further subdivided by gender, into adult women and men, to test a possible gender effect on land use change (as specified in H4). The second set of models, the column at the right of each dependent variable, includes all families in the lot (All), and is further divided into adults and dependents in order to measure their effect on land use.

The first pair of columns in each table specifies the effect of different independent variables on secondary growth. For 1992 none of the independent variables explained variation in secondary growth area between households. By 2002, although the variation explained by the models was low, they were statistically significant at the 95 percent confidence level or above ($r^2 = 0.094$ and 0.089 ; F ratios 1.972 and 2.060; $p \leq 0.05$). Direct relationships were found between the area in secondary growth and the overall area of the lot, the age of the household head and surprisingly, the number of adult women in the lot. The positive effect of the household head's age suggests that there is a life-cycle effect of expanding secondary growth in the later stages of their life cycle as predicted by the empty nester scenario in McCracken et al. (1999). However this was not linked to an equivalent increase in the number of dependents or in the dependency ratio as specified in H1.

Multivariate regression models that explore the change in the values of land use classes between 1992 and 2002 show an almost negligible effect of life-cycle indicators on secondary growth except for *change in household head* (D.5). This variable complements the positive impact that the variable *household head age (1992)* has on secondary growth, suggesting many households in the latter stages of their life cycle are in an empty nester scenario, with its associated abandonment of productive lands but not necessarily linked to an increase in the number of dependents and dependency ratio. Therefore the empty nester hypothesis (H1) is only partially sustained.

The third and fourth columns in each table represent regression models for the area allocated to annual crops. If we follow an empty nester scenario, the end of the life cycle should be associated with a reduction of annual crops while for a generational shift scenario the total area under crop production should increase. For both survey years, household demographic variables (number of families, number of adults [all] and number of men [F1]) are important determinants of the production of annual crops. In the case of using the difference between both years as the dependent variable, an increase in the number of families and number of dependents resulted in a proportional increase in the area allocated to annual crops. The positive effect of dependents is important since it confirms the generation shift hypothesis (H2) that claims that a generational change increases the demand for subsistence crops from within the household. However it is important to note that the positive relation between number of dependents and annual crops was only statistically significant in table D5. Therefore the evidence of an impact of the household life-cycle indicators on the production of annual crops is not considerable and is mostly linked to the availability of working-age household labor and less so to the internal demand from the household.

Also, neither *residence time on the lot* nor *age of the household head*, both related to the expansion of agricultural production for family consumption according to the generational shift version of the life-cycle theory (H2), was significant. However, in table D.5, a significant impact was found for *change of the household head* on the area in annual crops. Therefore, regression models suggest that in the case of household life-cycle variables, the production of annual crops is linked to the availability of household labor, to an increase in the number of dependents and to a change in the household head,

supporting the generational shift hypothesis over the empty nester scenario (H2 instead of H1).

Other variables besides household life-cycle variables were found to be significant for the production of annual crops. In 1992, market integration variables and the distance to the nearest market center were significant predictors of annual crop production as specified in H9 and H10. In the case of market integration indicators, annual crops were positively related to *hiring of day laborers* and to membership in agricultural *cooperatives*. In table D.5 the percentage of production sold was also positively associated to the expansion of annual crops. However, these associations are no longer present in the 2002 models, probably because agricultural markets changed and the reliance on annual crops for market production in relation to cattle has decreased considerably in recent years (Walker et al. 2000).

The fifth and sixth columns in each table present the perennial crops models. As in the case of annual crop production, significant life-cycle variables are represented by the availability of adult labor. Lots that had more perennial crops also had a larger number of families, total-adults and adult-men. Other household life-cycle variables such as the effect of the number of dependents, age of household head or years on lot were not found to be significant although they are theoretically important variables in explaining the production of perennial crops. The exception was the unexpected negative effect of the age of the household head on perennial crops in 1992 (table D.1), which suggests older household heads could have been experiencing an empty nester scenario as early as 1992. The lack of expected significant positive associations between perennial crops and the variables time on the lot and age of household head might be due to the decreasing importance of perennial crops as a source of income and their gradual replacement by other land uses such as pasture bringing into question the conventional models of the household life cycle.

Besides the life-cycle variables, households had more land in perennial crops if (1) they had larger properties, (2) they participated in mutual help associations, (3) they sold most of their production, and if (4) they hired day laborers. Being a labor-demanding task, it was expected that households that engage in labor sharing, mutual help associations, would be able to expand their area under production. Market integration

indicators such as the percentage of production sold and the hiring of day laborers are positively linked to the production of perennial crops in both study years. This was expected since most of the perennial crop production is produced for market. Finally, the positive association between property size and area under production planted to perennial crops demonstrates once more the extensive nature of agricultural production in the Amazon which requires vast expanses of areas per household to be economically competitive, confirming the importance of looking beyond household life-cycle indicators to explain land use change processes.

An interesting significant relation was the negative relationship between the percentage of deforestation on the lot in 1992 and the increase in perennial crop production during the study period (Table D.5). Since no effect was found between the variables that indicate a life-cycle stage effect (*years on lot, residence time in Rondônia or household head age*) I could not confirm that this was due to households arriving at the frontier later. An alternative explanation is that other contextual lot factors not examined in this study (e.g., soil quality) might force some farmers to expand into productive crops later in time than other farmers, explaining why those who had less deforestation in 1992 expanded their area for perennial crops farther during the next ten years.

Columns number seven and eight present regression models for pasture land use. As expected from household life-cycle models, in 1992, larger areas allocated to pasture were related to less working-age adult members (adults and men) since pasture is a less labor-intensive activity than crop production. Contrastingly, a lower dependency ratio was associated with larger areas of pasture during both study years (a lower dependency ratio requires an increasing proportion of adults to dependents). These seemingly contradictory relationships can be solved by examining the life-cycle theory. According to this theory the production demand for subsistence needs within the household has to be met before expanding into other economic activities. Therefore, as a household moves along its life cycle its dependency ratio will diminish, reducing also its dependence on subsistence crops and expanding its market-based activities such as cattle raising hence the negative relationship between dependency ratio and pasture. On the other hand, productive economic strategies are constrained by the availability of adult labor within the household. Once a household fulfills its demand for subsistence crops, it can shift

towards market production activities, but those that have limited labor availability will prefer less labor intensive activities such as cattle raising to more intensive ones like perennial crops. While the first relationship is linked to the stages of the life cycle, the second stresses the relation between labor constraints within life cycle stage and the productive activities chosen.

Another interesting trend that can be observed from the pasture regression models is the relationship of household head age and the expansion of pasture. In the 2002 regression model (table D.2), household head age appears with a significant negative relation to the extension of pasture that is not evident in the 1992 regression model (table D.2). This negative relationship is confirmed when I examine that the greater expansion in pasture formation between both years is associated with the younger household heads in 1992 (tables D.3 and D.4). The only exception came after introducing the variable *change of household head*, which is negatively associated with pasture expansion, indicating that those households that suffered a change in their household head later abandoned part of their pasture. However, the association of younger household heads with the expansion of cattle requires another explanation. As hypothesized earlier, this is probably linked to a later migration wave into the region, characterized by younger households with better economic capacity and more prone to invest in cattle than their earlier counterparts. This group will be better equipped to invest in cattle raising activities and consolidating lands in the region to expand their cattle investments as is shown by the positive effect of increasing lot size with pasture formation (table D.4).

Another significant variable across both study years was the positive effect of the area of the property with the expansion of pasture, an effect expected due to the extensive requirements of cattle in relation to other agricultural production strategies. For the 1992 survey other significant variables included market integration variables, specifically *participation in cooperatives* and *hiring of daily workers* which were no longer significant in 2002.

The last two columns, in each table, represent regression results for the area remaining under forest cover. Unlike the previous set of regression models that predict the allocation of land towards different land production strategies, these models reflect the maintenance of areas under forest cover. This is usually associated with household-

level constraints to convert forest land into other forms of production. This is confirmed in the 1992 survey where both the number of families and the overall adult labor force were negatively related to the area of primary forest in the lot. However, these variables were non-significant in 2002 probably due to the expansion of land from several households considerably increasing their area under forest regardless of their ability to convert these into production.

Examining the regression models that attempt to identify the variables predicting the loss of forest cover over time, I can conclude households were more prone to have larger areas under forest if (1) they had younger household heads, (2) had lived on the lot for a shorter period of time, and (3) had a higher dependency ratio. These three household life-cycle indicators confirm conventional household life-cycle postulates that deforestation will increase with time as the household moves through its life cycle. The dependency ratio was significant and positive, which suggests that subsistence demands in the initial stages of the life cycle inhibit loss of forest. However, contrary to expectations, equivalent changes in the availability of adult labor were not found in the regressions models that predict changes over time (tables D.3, D.4 and D.5).

Two other variables that are not considered life-cycle indicators had an important impact on the forest cover regression models, specifically, the negative effect of the variable *hiring of day laborers* and the positive effect of *area of all properties*. The significant negative impact that *hiring of day-laborers* has on forest cover reflects the capacity of the household to pay for additional clearing of land but is also an indicator of market integration and the need to expand the area under production as the household becomes more dependent on cash crops and less on the production of crops for family consumption. The size of the area will have a positive effect since most farmers consolidating land are acquiring land that has more forest cover, increasing significantly the proportion of forest in their landholdings.

Discussion and Conclusions

This chapter examined the degree to which household life cycle and other demographic variables may influence land use change strategies. Findings from the regression models present mixed results regarding the practicality of the household life-

cycle theory in explaining land use change processes. While I find some evidence that household durations of ownership, age structures and the type of scenario that unfolds as the household reaches the end of its life cycle (empty nesters or generational shift) have an impact on land use change processes among small landholders in Rondônia, their ability to explain the variability found is low. Results reveal that household life-cycle factors have diverse and complex effects on land use allocation that cannot be properly represented in conventional regression models. Furthermore, other theoretically important variables tested also explained little of the total variation found in the field. However some lessons can be obtained and applied in future research and policy prescriptions. First I review the cross-cutting results in an attempt to link regression results from the different outcomes or land use classes to the household life-cycle theory. This will allow us to gain a better understanding of the interrelationships between them and between life-cycle factors and other important types of theoretical factors.

Regression results confirm the life cycle theoretical postulate on the role of labor as a critical constraining production factor. Households with more working-age adult labor showed greater expansion of land in all production output categories: annual crops, perennial crops and pasture. Across regression models it was the most consistent factor explaining land use outcomes. Interestingly enough, the hired-labor variable led to greater amounts of primary but not secondary forest-clearing. Furthermore, off-farm income was correlated with less forest clearing in 2002 but not in 1992, nor did it correlate with less forest clearing expressed as a difference between 1992 and 2002 (Tables C.1, C.2 and C.3). However, once inserted in the regression models, the variable was not significant across any of the dependent variables and was removed in favor of other more relevant variables. Therefore, although labor is a constraining factor for production-level outputs, we cannot conclude that creating off-farm employment opportunities will lead to less deforestation and more intensive land use practices at the farm-level as suggested in other studies (e.g., Yanggen 2000; Vosti et al. 2002).

Lot context features, in our case the size of all the household's properties and the distance to markets also impacted land use outputs. As expected, the area of all properties has a positive relation with the area allocated to different land cover types. As specified in H10, in 1992, the distance to the nearest market center had a negative

relationship with productive outcomes (annual crops, perennial crops and pasture) and a positive relationship with forest area but not with secondary forest. However none of these relationships were present in 2002 and were weak predictors of change between 1992 and 2002, with the exception of a significant positive impact on secondary growth. Overall, results are mixed and the interaction of *distance* with other factors is probably important in order to determine its effect on land use since there was a differentiated impact for the different subsamples tested.

Social participation indicators did not result in important land use outcomes as predicted in hypothesis H6. A notable exception was the positive significant relation between mutual help associations and perennial crops. However, for the other regression models and land use outcomes, results were not statistically significant or did not correspond to expected results. It is not clear if in fact the social participation proposed in H6 will lead to more sustainable land use outcomes suggesting other verification methods should be tried in order to determine possible impacts of social organizations on land use outcomes over time.

Wealth is believed to have a differentiated effect over time as described in hypothesis H8. Results for wealth indicators over time were almost negligible and when significant it did not present the inverted U-shape hypothesized by Godoy (1997), described in H8. In one case wealthier households were associated with an increase of secondary growth and in a second case, with an increase of pasture, both showing an opposite relationship than expected in an end of the household life-cycle scenario. Therefore I would refute H8 in light of the negligible and contrary findings from the regression models.

Market integration indicators showed more important relationships with land use outcomes than most of the other groups of variables described above. Independent of the life-cycle stage of the household, farmers that are more integrated into the market should have larger areas allocated to the production of commercial activities (specifically pasture and perennial crops) and a reduction of the area for subsistence activities such as annuals and secondary growth (H9). Results partially support the hypothesized relationships. While significant positive relations were found between the expansion of perennial crops and market integration indicators, this was not true for pasture. Market integration

indicators varied in their effect on pasture. While the indicators *participating in cooperatives* and *hiring of day laborers* were positively associated with the expansion of pasture, the *percentage of production sold* was negatively associated with pasture. However, *percentage of production sold* is probably a better indicator of market integration in relation to agricultural crops than in a more medium to long-term activity like cattle raising. Also, many smaller farmers increase their pasture area to rent to overstocked cattle owners, a type of economic transaction that is not reflected in percentage of production sold. Overall, I conclude that market integration variables are a good predictor of land use outcomes and regression model results seem to confirm H9, however better indicators might be needed in the future.

The relationships between land use dynamics and household life-cycle indicators was mixed and in some cases negligible. As a review, household life-cycle variables can be classified into four types of indicators: (1) variables that determine adult labor availability (e.g., all adults, adults males), (2) those that determine the number of dependents (number of dependents, dependency ratio), (3) those that measure the influence of gender roles (number of adult women) and (4) those indicative of time spent on the lot (years on the lot; age of household head). The explanatory significance of these variables over time and across land use classes varied considerably, reinforcing the importance of the changing role of life-cycle variables over time.

Across household life-cycle indicators, variables that determine adult-labor availability were discussed first because of the relative importance they attained compared with the other indicators. Also, I wanted to emphasize their importance in determining output land use classes as a function of adult labor-availability and not necessarily as life-cycle indicators. A similar case can be argued for the number of dependents and the dependency ratio, however the effects of these variables was almost negligible. According to H1 and H2, the dependency ratio should increase if there is an out-migration of young adults from the farm (empty nester scenario) or if there is a generational shift as the original household head's age advances and younger adults have children of their own. In the first scenario, productive areas would decrease and secondary growth increase, while in the second, subsistence demands from children will lead to further suppression of secondary growth and expansion of subsistence-based

crops, specifically annual crops. However, regression models confirm neither scenario, finding only a negative relation between dependency ratio and pasture. Therefore households that have a high proportion of dependents in relation to adults will have a low capacity to maintain or expand into pasture but it is not clear why the same was not found for production crops (e.g., annuals and perennials). Since the household life-cycle model has theoretically linked the number of dependents and the dependency ratio to subsistence-based farm production, results that reinforce the importance of adult labor for crop production but not for equivalent changes in the dependency ratio or the number of dependents, suggests production is being directed almost exclusively towards market-based products and not to fulfill subsistence needs. This seems to be occurring even when families have a high dependency ratio or number of dependents.

The third set of household life-cycle indicators measures the impact of gender roles on land use outcomes. The number of women was hypothesized to impact positively on the amount of land allocated to annual and perennial crops. However, since no relationships were found in the regression models tested I have to reject H4 and suggest other methods should be used to determine the impact of gender on land use outcomes.

The fourth set of household life-cycle indicators is probably the most important set of variables since they are the ones that most directly determine the position of a household in its life cycle. These variables include resident years on the lot and age of the household head. Although I take both as indicators of the household life cycle, other authors, specifically Barbieri et al. (2005), have suggested they are in fact different since the first is an indicator of the farm life cycle and the second of the household life cycle. I follow earlier models that consider both as indicators of the household life-cycle. Furthermore, I used the variable *years on lot* and *years in Rondônia* interchangeably depending on which gave better results for a set of regression models. According to the household life cycle theory, by the end of their life cycle, *household head age* and *years on lot* will be directly related to secondary growth and negatively related to annual crops and pasture while perennial crops will be maintained for some time (H1). An alternative scenario claims that if the young adults stay on the farm, *household head age* and *years on lot* will be positively related to the production of annual and perennial crops and negatively associated with pasture. Both showed weak relations between these variables

and land use outcomes. Despite their weakness by regression model standards, *age of household head* had a more significant impact on land use outcomes than *years in Rondônia* and *years on lot*. Older household heads had a significant negative relationship with pasture and a positive one with secondary growth, confirming that as households reach the later stages of their life cycles, secondary growth expands and pasture is abandoned. This seems to confirm the empty nester scenario whereby young adults migrate, leaving the elderly on a declining farm estate.

However, the negative relation between household head age and pasture can also be due to a growing interest of younger household heads to shift their production systems towards cattle. This was suggested earlier and could be due to one of the following reasons; (1) a second wave of migrants that arrived later in the frontier process with more capital and interest in investing in cattle, or (2) younger adults, with a stronger interest for investing in cattle, become influential on land management decisions. It could also possibly be a mixture of both. However, in both cases there is a generational factor whereby younger household heads are more likely to raise cattle than older household heads that identify themselves as farmers and not ranchers. Interviews with farmers in the region confirmed that younger household heads were more interested in expanding into cattle than their predecessors. Even those that were not actively engaged in cattle ranching envisioned it as part of a longer-term strategy.

A final household life-cycle related variable is the *change in household head*. This binary variable was introduced to check the possible impact that a change of household head would have on land cover classes. According to the generational shift scenario, as the elder generation passes control to the next generation with young children, renewed demand for subsistence would reduce regrowth, increase and renew annual crops instead of maintaining pastures and perennial crops. The generational shift significantly increased the area in annual crops but also the area in secondary growth and pasture was impacted negatively. Among the life-cycle indicators, it was one of the best predictors of land use change suggesting the importance of considering the generational change as a major factor impacting land cover classes. However, while the generational change assumes reverting back to the initial stages of the life cycle, it must consider land use classes and resources are in a very different state than in the initial stages of the original household.

The results provide little support for the reliance of the household life-cycle theory for explaining land use change, although some evidence suggests there is an impact, this impact is not far-reaching and regression models could only explain a small percentage of the variation found. Overall, hypothesis H0 would have to be refuted in the light of scant evidence that the household life-cycle theory is relevant in the emerging Rondônia post-frontier scenario. Other theoretically important variables were tested but also showed mixed results and explained little of the variations in the outcome for different land cover classes. Results seem to suggest that the theoretical model introduced in chapter 2 holds true for the later phases of the Rondônia frontier. As the whole economy starts to shift towards the specialization of cattle, labor and capital constraints relax and the relevance of household life-cycle factors diminishes. In order to promote appropriate policies towards more sustainable land use practices, researchers need to shift away from the demographic and household-level factors of farmers and turn their attention towards the real drivers of land use change; specifically, exogenous factors that promote the adoption and expansion of pasture among small landholders.

Despite the limited significance of the factors explored some trends were found that have important policy implications. One of the important findings suggests that although adult-labor is a key constraint in expanding agricultural production rates, allocating labor away from farms by promoting off-farm work opportunities will not necessarily reduce deforestation rates. Results show that income that is earned from off-farm work is later reinvested in the farm to open up additional areas for pasture expansion. The simplistic solution that if labor is allocated away from the farm, deforestation rates will be reduced does not lead to lower deforestation rates or a more sustainable landscape while the earnings are not reinvested in the expansion of pasture lands. The drive to invest in cattle comes from beyond the confines of a single household. Based on interviews during the second field work period revealed that the high stocking rates of larger cattle ranchers in the sample, and land constraints to expand within the region, has led them to promote pasture planting among neighbors to rent as need arises. In fact, while the presence of cattle from third party members was negligible in 1992, by 2002, 13 percent of farm households were renting pasture and 17 percent of the total cattle herd within the study areas corresponds to non-lot members. In order to deter

deforestation, land degradation through pasture formation and consequently forest turnover rates promoted by the opening of new frontier fronts, policies should be aimed at discouraging cattle raising as the only feasible long-term investment opportunity. Alternative land use strategies such as agroforestry and timber management in forest remnants should be promoted through subsidies that can cover the costs of competing on a land use basis with cattle farming. Payment for environmental services schemes could promote these changes by covering the costs of these alternative land use practices.

CHAPTER 7

CONCLUSIONS

The Amazonian frontier has been associated with dramatic images of rampant deforestation and violent land conflicts. The Brazilian state of Rondônia drew special attention since it was the setting of a World Bank-funded colonization project to benefit landless farmers from other regions; one of the first to take into consideration environmental and social aspects during the frontier settlement process. This dissertation used a longitudinal panel survey to examine social and environmental consequences of three frontier settlements in the present context, 15 to 25 years after the initial colonization and the beginning of its post-frontier phase. Despite initial widespread criticism and doomsday predictions of an ecological disaster, smallholder farmers have persisted as viable, and in many cases successful, agricultural entrepreneurs in the frontier. However, frontiers have not stabilized and deforestation continues in the original colonist settlements and farther out on new frontiers with growing expectations of future infrastructure development. While, on one hand, the frontier appears to show a consolidation stage in the smallholders' production system, on the other, regional deforestation problems continue and the long-term sustainability of smallholder farmers is still in question.

The sociopolitical context that characterized the initial colonization fronts of the 1970s and 1980s is very different from the present context that is driving farmers from the now colonized frontiers further out into the new frontiers which are being deforested in the 1990s and the 2000s. I revisited the household life-cycle theory and presented a conceptual hybrid model that links the household life-cycle theory with frontier successions and hierarchical models, stressing connections with the later stages of the household life cycle for a better understanding of the relation between land use change and the evolving post-frontier context in Amazonia (Figures 2.3 and 2.4). I examine my findings within the major theoretical debates in the development and conservation literature on Amazonia. I then attempt to link the major findings of this study with

appropriate policy prescriptions to curb current deforestation rates. Finally, I review the implications of these findings for future research.

Summary of Results – Major Findings

Conventional models based on the household life cycle theory assume the agricultural frontier is made up of a relatively homogenous group of farmers whose changing land use strategies over time correspond to changes in their demographic household structure as they move through their life cycle. My findings reveal a much more complex story. As the frontier ages and becomes a post frontier, the small landholder is forced to adapt its land use strategies to address a range of emerging regional and global factors well beyond its own immediate environment and demographic structure as proposed in the household life cycle theory. Original farmers see themselves competing with a new set of land owners who are characterized by being younger, more capitalized, usually urban-based, and who are buying up land and cattle as a way of diversifying their existing investments. The resulting post-frontier shows an increasing socioeconomic differentiation of small landholders, an increasing articulation of urban and rural homesteads, and the emergence of regional and global markets for a diversity of Amazonian-produced products, especially cattle, as driving forces of land use patterns among small landholders.

While the household life cycle theory relies on land use strategies for the survival of the household, the study found an increasing array of off-farm forces shaping land use strategies, therefore limiting the capacity of a theoretical framework based solely on on-farm characteristics as the major feature shaping their livelihood. Findings from this dissertation reject the hypothesis that land use practices correspond to the changing demographic structure of the household as it moves along its life cycle stages. The following sections review major findings by chapter and then return to the broader issues and lessons learned from this study.

Chapter 2 underscored the evolution of the frontier concept in the literature and analyzed the assumptions, postulates and trends of different theoretical frameworks. After reviewing some of the difficulties of pursuing a life cycle theoretical model in the context of the emerging post-frontier Amazon setting I introduced modifications to the theory in

order to consider emerging differences in property size and ownership patterns. Specifically I introduced an extension to the household life cycle model to explain property fragmentation and consolidation processes and property turnover (Figure 2.3). In few words, as the household reaches the end of its life cycle, a new generation of families within the household will require land of their own. The ability of a household to expand and accommodate the growing number of families members, remain stable or be forced to fragment will depend on a range of factors that can be summarized in the following two; (1) a favorable family demographic structure (low dependency ratio and high number of adult men laborers), and (2) the relative success of the household in the past (wealth accumulation, including land and cattle).

On a broader theoretical scale I attempted to contextualize the relevance of the household life cycle theory along the different phases a frontier moves through and across space at different scales of analysis. I rescue the concept of frontier successions or phases as presented by Carl Sauer in his frontier studies as opposed to the linear stages as they appear in the household life cycle theory and frontier stages models. Although frontier successions recognize that a frontier moves through a series of different phases, these do not occur in a linear and predictable fashion but instead are the resolve of the dialectic relation between the environment and human agency. Comparing the Rondônia study sites with other frontier processes across the Amazon what emerges is not a convergence of social and landscape patterns over time. Instead of predictable stages uncertainty characterized the emerging social and land use outcomes, instead of simple linear patterns we found complexity and multiple pathways of land use across farms and instead of homogeneity we found heterogeneity across farmer profiles over time. While all small farmer frontiers start with an autarchic independence from exogenous factors, they inevitably diverge into different social and landscape as the frontier articulates itself to different regional and global processes. My proposed alternative theoretical framework claims that as the frontier moves through a different set of successions or phases the household life cycle factors will become less relevant for explaining the social and natural landscape of the next successional phase.

Chapter 4 reviewed the major historical phases through which the Amazon region has been colonized, and concluded that despite the effort to install development schemes

that favor a small landholder farmers these have not been successful in promoting a sustainable form of livelihood that is autonomous of larger capitalist movements. Furthermore, social and environmental impacts put into question the longer term sustainability of a small landholder farmer system of production as the frontier moves into a post frontier scenario. Since the 1990s, Brazil has emerged as a superpower in the global cattle market, which has increased the demand for cheap land for pasture lands, especially important are the consolidating frontiers, which can be easily accessible through existing infrastructure and still maintain an abundance of cheap land for pasture. Therefore, the increasing expansion of pasture seems to be not driven by aging household life cycle factors, but is the result of the articulation of the agricultural sector in Rondônia to this emerging global cattle economy. Findings from the statistical analysis in chapter 6 confirmed the weak links between life cycle factors and pasture formation in the present post frontier context.

Chapter 5 presented a detailed study of two aspects that had been elusive in conventional land use studies; the fragmentation and expansion of household landholdings and household ownership changes. One of the major proposed modifications to the household life cycle theory that I presented in chapter 2 was that these processes of household property size and ownership changes could be explained using this theoretical framework. Empirical analysis of the cross-sectional panel data set confirmed initial field observations of very dynamic frontier processes regarding property size and land ownership. Processes of land expansion and reduction were both equally important (18.4 percent of households had subdivided their landholdings while 19.3 percent had expanded their land) but since the aggregations were usually of noncontiguous land and disaggregation is constantly fragmenting existing management units; the spatial configuration of the frontier increases in complexity from its original grid-like patterns to a slightly more fragmented landscape. The analysis of property ownership showed more stable figures, with 72 percent of the households surveyed in 2002 corresponding to the original households surveyed in 1992 although 18 percent of these had experienced a generational transition of ownership. Regression analysis confirmed that the changes associated with property size and ownership changes were linked to demographic variables, specifically labor constraints, but these, were not found

to be associated with the end of the household life cycle. The appearance of a relatively new group of more recent owners embedded in the sample—younger, wealthier non-farmers with an interest in the establishment of cattle ranching—increased the complexity of establishing a household life-cycle model to explain land use changes in the region.

This study found several alternative scenarios for a household reaching the end of its life cycle. In one scenario, wealthier households are able to expand their existing landholdings and accumulate cattle as assets to pass on to the new generation of farmers. A second scenario is characterized by those that reach the end of their life cycle in poorer conditions and are therefore forced to fragment their property among the emerging number of families within the household. A third scenario, also linked to the households at the poorer end of the spectrum, found whole households moving farther out into new frontiers.

The opening of new frontiers not only lured whole households but partial migration has become just as important; wealthier households send their younger members to expand cattle holdings into new frontiers while younger members in poorer households venture to these new frontiers in search of land. The household decisions regarding property expansion or fragmentation and property ownership were not only linked by the internal household characteristics but even more by emerging region-wide trends in economic opportunities, especially rising global demand for Amazonian beef and the opening of new frontier lands. To this we add the increasing demand of an urban middle class in the existing study sites, to acquire rural land as a form of investment. Therefore, trends in property size and land ownership are not exclusively linked to the life cycle per se but are shaped by opportunities and constraints influenced by local, regional, national and even transnational forces.

Although the household life cycle underlies the opportunities and constraints that arise over time within the household, final land use decisions and the evolving landscape are ultimately shaped by other factors that are operating at different scales; local (history of the settlement, biophysical conditions), regional (opening of new frontiers due to the expansion of logging roads, infrastructure development programs (IIRSA), economic growth of urban centers), national (increasing markets for cattle, fiscal policies) and international (pressure to conserve primary forests, indigenous lands, etc). This multilevel

set of interactions increases in complexity as the frontier becomes further articulated with national and international forces (e.g., markets for timber, soybeans, cattle). The result is that the existing spatial structure and property dynamics (size and ownership) that is unfolding in the post-frontier is far from stable and uniform and is rather highly dynamic. The study sites show themselves to be part of a more complex tapestry of frontier spaces that are differentially articulated to each other and to other regional, national and international factors. The processes found in property size and ownership can only be understood once we factor in the broader processes with which they are economically and socially articulated. The conceptual diagrams introduced in chapter 2 (figures 2.3, 2.4 and 2.5) are an initial effort in this direction.

Chapter 6 empirically tested household life-cycle variables that determine land use strategies and how these compare with other theoretically important variables. Relations between the different household-level factors and land use strategies indicate that in fact there are several commonalities across households that characterize different successions of the frontier process but these do not explain much of the land use variation found at the household level. Therefore, while the household life-cycle theory is important as a framework to understand the changing role of household level factors over time in determining land use strategy changes, it falls short of explaining the complexity inherent to modern agricultural frontiers. Instead, the household life-cycle theory should be used in conjunction with other theoretical models that will allow complementing and properly contextualizing the role of household life-cycle factors.

More than implicitly proving or disproving the household life-cycle theory I suggest adopting a conceptual pluralistic perspective, allowing the possibility that different frameworks explain different aspects of the post-frontier. For example, the household life-cycle theory is clearly important for understanding land use change patterns between households over time but not for explaining the divergence in land use strategies between sites despite their similar length of time since colonization (which would require examining regional factors). The household life-cycle theory has to be contextualized within a broader set of theories that are necessary to complement and mediate the influence life-cycle variables will have on land use decisions.

The household life-cycle theory modifications introduced in chapter 2 (figures 2.4 and 2.5) is an attempt to adapt the household life cycle to the pluralism and complexity that characterizes the present-day post-frontier. The weak links found between household life-cycle theory and changes in property size, ownership and land use classes do not necessarily mean the life-cycle postulates are obsolete, but rather that they are incomplete. The model presented in chapter 2 was found to be useful in conceptualizing the changes associated with the different successions that a frontier goes through, especially the impact of life-cycle indicators over time. While not subscribing to a predictable linear frontier stages model, I acknowledge the existence of successions or phases through which the frontier passes, which, to a certain degree, indicate the impact of different factors shaping property-level changes. The household life-cycle theory is an important theoretical lens for analysis but its impact has to be contextualized within the successional phases occurring in the study sites. Understanding the historical and biophysical characteristics that shape these successions and their interrelation with the life-cycle postulates is more important than trying to develop an overall theoretical paradigm that can explain land use change processes. The suggested post-structural framework considers that the defining characteristics of the frontier will be peculiar to the region.

The findings of this dissertation also contribute to ongoing debates on development and conservation planning issues. The following sections examine the findings in light of some of these issues introduced in chapter 3.

Agricultural development: The sustainability of the small landholder farmer

Are smallholder farmers a viable and sustainable development option for Amazonia?

One of the most persistent questions in rural development has been the viability of small landholder farmers on the frontier. The modern occupation of Amazonia (reviewed in Chapter 4) has been characterized by policies that have shifted back and forth between discourses supporting small farmer settlements or populist frontiers and those favoring large landholders and corporate frontiers (Browder and Godfrey 1997). Small landholders, unlike the dire predictions regarding their fate in the Amazon, have not only

survived but flourished, there being almost 750,000 farm establishments of 100 hectares or less in the Amazon region (Vosti et al. 2002). Furthermore, unlike the vision of stagnating poverty, small-scale farming systems in Rondônia are generating sufficient income to sustain themselves and further expand production levels, as well as contributing to regional economic growth (Ozorio de Almeida 1992; Faminow 1998; Andersen et al. 2002). However, this picture is incomplete without considering the highly uneven distribution of economic benefits and the high environmental costs of predominant land use practices.

While the smallholder farm has successfully established itself as a viable unit of production in the western Brazilian Amazon, it is still far from reaching a consolidated and stable stage; smallholder farmers appear to be a very dynamic class. There is also evidence of increasing class differentiation over time. Current trends suggest that some smallholders are expanding their land holdings, while others are forced to fragment their properties; some are diversifying into urban activities while others are specializing in cattle ranching activities. All this is driven by active markets for cleared agricultural land, fueled by economic growth of urban centers whose rising middle class buys land and cattle as investments (Ozorio de Almeida and Campari 1995; Browder and Godfrey 1997). The availability of land further out on the frontier and the increasing population growth within the region, which also demands land of its own, has set in motion the internal economic dynamics and land markets for the opening of new frontiers. The increased turnover rate of agricultural land due to the opening of new frontier regions and expanding urban economic elites, synergistically linked to the growth of cattle herding in Amazonia, is found to be the single most direct underlying cause of current deforestation rates in the Brazilian Amazon.

As long as land is treated as another commodity to be exchanged on the market there are low incentives for farmers to invest in longer-term environmental management practices on their properties. Policies that are aimed at reducing the capacity of small landholders to sell and buy land and limit land speculation could serve as incentives towards more sustainable land use practices. Furthermore, it is imperative that the Amazonian frontier finally closes in order to prevent further rural-rural intraregional migration of small landholders which only produces further deforestation on the new

frontier and catalyzes land degradation practices in the post-frontier regions. Higher transaction costs and reducing the opening of new frontier zones will increase land prices and the inherent longer term value of land among small landholders.

I conclude that current land use practices of small landholder farmers are unsustainable but they do not need to be so. Promoting changes in land use practices will have to take into consideration that what is guiding unsustainable land use practices is not ignorance of conservation or appropriate land management practices but the larger context of land and cattle markets that act as an economic incentive to increase property turnover rates in old frontiers and forest clearance in new ones. Policies that can reward small farmer agriculture, that is those that increase agricultural productivity and invest in more sustainable land use practices, should be encouraged. Increasing agricultural productivity should reduce property turnover rates and make it more competitive. Incentives to adopt more sustainable land use practices might benefit in the near future from developing Payment-for-Environmental Services schemes. However, in order for these to become feasible, pervasive policies that encourage cattle ranching, land speculation and the opening of new frontier areas also have to be controlled.

Regional Planning Implications

Colonization schemes, growth pole centers, infrastructure development and state subsidies were all important regional planning instruments to promote growth and development in the hinterlands of the Brazilian Amazon. This study focused on one of the major transects of development projects in the Amazon, crossing the heartland of Rondônia. Unlike other major transects, this region's development planning focused on promoting small-scale agriculture and included critical social and environmental aspects during its execution (specifically the POLONOROESTE and PLANAFLORO projects partially funded by the World Bank). What have been the implications 30 years later and what can the lessons learned contribute to development planning theory and practice?

As reviewed in the previous section, smallholder farmers have benefited economically in the long run from these colonization programs. Despite this economic appreciation, social and environmental costs have been strikingly high. The lack of political will at the local level to implement environmental zoning constraints and the

lack of state-level agencies to control the massive levels of immigration call into question the sustainability of top-down approaches to development planning, especially in frontier regions with poor governance structures and limited social capital levels. Government officials envisioned frontier settlement as a strategy to increase agricultural production levels and attend the demand for land reform in other Brazilian regions. The environmental and social issues were conditioned by World Bank loans through international pressure; they were not the priorities of the Brazilian state. The end result was the lack of political will to implement these policies, despite continuous international pressure. The present-day landscape is the result of the original planning schemes to condition settlement to appropriate ecological-economic zoning parameters and the ruthless appropriation of lands and colonization programs on the part of land speculators associated with local elites whose economic interests lay in taking control of the economic benefits associated with controlling land. These two forces have been conditioned by the unrelenting strategies of small landholder farmers to persist on the frontier, despite pressure from land speculators and businessmen to take over their lands.

As we move into the new century a new process of land appropriation and frontier dynamics has emerged. New development projects such as the IIRSA (Integration of Regional Infrastructure in South America) transportation investments of the Inter-American Development Bank and the Madeira River waterway complex project, which would connect the main channel of the Amazon River to Rondônia and Bolivia, will make accessible the vast core region of the Amazon basin, until now largely isolated and sparsely populated. The economic barriers and relative isolation that prevented the occupation of most of the Amazon are rapidly disappearing. In order to mitigate the human impacts of frontier colonization on previously inaccessible forest that these projects will open up, it is imperative that the lessons of past development projects be applied.

The analyses in chapters 5 and 6 have shown the highly dynamic nature of property ownership and land use strategies in a post-frontier context. As land markets appear for previously inaccessible forested frontier regions, new generations of farmers from previous frontiers migrate, while others sell or fragment their holdings in order to buy cheaper land further out on the frontier. The effects of these unstable frontier patterns

of land tenure on land use and deforestation were reviewed in the previous sections. Unless policy instruments to discourage land deforestation through the expansion of existing frontier regions can be set in place together with political will and strong governance structures, IIRSA and other massive development projects will soon become the center of new deforestation fronts over the broadest area of the Amazon region since the beginning of the migration periods in the 1970s and '80s.

The story of Rondônia highlights the failure of top-down development approaches for organizing colonization schemes in the Amazon region. While previous colonization programs were characterized by a strong planning component, in the current scenario it is expected that the state will favor a more hands-off approach in allocating colonization sites, favoring private investments as opposed to state-controlled planning. Katzman (1978:56-79) has shown how these could be more efficient than state-sponsored colonization programs. However, unrestricted colonization will result in further land speculation and land appropriation schemes, leading to further land conflicts and high deforestation rates. Therefore, if the state wants to seriously consider controlling the upcoming deforestation fronts and social equity issues associated with the expansion of infrastructure projects, it will have to act, especially in the design and enforcement of zoning restrictions. It will have to be more creative in its approaches, investing more time and resources for a more decentralized planning approach and involving local populations. Instead of directly trying to allocate land parcels through a federal agency (INCRA MODEL), government efforts should start by building up social capital and enforcement capacity in the frontier, especially empowering local level capacity for governance. Also, the state should try to take advantage of existing civil society groups already in place in the region who can be more effective in securing local level participation for mitigating the impacts of colonization. While civil society groups can be important allies, political support and working with the state will be necessary for securing accountability.

Rain forest conservation

What are the mechanisms for promoting rainforest conservation at the small landholder level?

Under current political and economic conditions deforestation rates will continue. Study sites showed that only 35 percent of the original forest remains in these post-frontier regions. Still, agricultural returns for labor continue to be higher than those obtained from forest extraction or from maintaining forest remnants. So, while smallholder farmers have benefited from increasing incomes over the 30-year period since their arrival, they do not have incentives for retaining natural forest cover or intensifying production in smaller areas. On the contrary, our results support initial observations that suggested farmers are expanding unsustainable land use practices over larger areas, including the acquisition of additional land in opening agricultural frontiers. Therefore, while technical and management practices that retain more biodiversity and conserve soil productivity do exist, in practice these are not being applied on any considerable scale. Equally important, policies could influence these management strategies, but, in practice, there is very poor political will to implement these at the local level.

Since current agricultural practices on cleared land are profitable, convincing farmers to deforest less will not be easy, and at larger scales, extremely costly. Still, based on the economic valuation of the environmental services they provide, globally and regionally, social gains could outweigh forgone economic growth by not deforesting (Costanza et al. 1997; Margulis 2004). Still, mechanisms for realizing these transfers exist on a very small scale, and due to a lack of political will on the part of strong economic interests, they will probably not be easy to implement in the near future. Economic models show that if credible mechanisms are put in place for compensating farmers for forest retention, smallholder farmers will respond (Margulis 2004). The lack of political will to implement policies that can diminish deforestation and promote appropriate land use practices continues to be the major impediment to a more sustainable landscape.

An emerging possibility for encouraging conservation practices at the farm level is the expanding market for Payment-for-Environmental-Services (PES) schemes. If we can estimate the additional cost of farmers to implement more sustainable land use practices at the farm level (e.g., maintenance of riverine forests, live fencing, organic farming, etc), market devices can be created to pay for these extra costs. Rewarding

farmers for better land use practices through private markets that are politically supported at the local level, with a matching effort to implement more strict zoning of land use practices might be a better approach than past command-and-control efforts.

Policy Prescriptions

The sustainability of small farmers will depend on an appropriate policy package that is sensitive to regional and local differences. Despite the combinations of policy instruments, the overall objective across sites must be to promote the intensification of agricultural production, support sustainable production systems (e.g., agroforestry, silviculture) and penalize rampant deforestation and speculative land transactions. Based on the Rondônia case studies I suggest the following.

The first prescription will be to “close” all existing frontier areas within the Amazon region allowing further settlements only where land is sufficiently productive for sustainable agricultural production. As long as land is available, incentives for land speculation and intraregional migration will persist. While some lands are fit for agricultural production (42 percent of land according to the current zoning plan of Rondônia) and should be zoned accordingly, it is equally important to close easily accessible areas with uncertain land tenure regimes. Agrarian reform should accordingly reallocate extensive properties not under production for protected or agricultural settlements. Indigenous reserves and protected areas should be expanded and appropriate funds for enforcing their protection allocated. Economic-ecological zoning has been applied in Rondônia at the 1:500000 and at the 1:250000 levels but critical localities require further zoning at the 1:50000. Furthermore, intraregional processes from Rondônia to neighboring states like Mato Grosso, Acre and Amazonas require that zoning parameters are established outside of Rondônia also. The economic-ecologic zoning instrument could effectively “close” existing frontiers but without the additional funds and political will for enforcing these, they are in danger of existing only on paper.

Second, ecological-economic zoning instruments should be coupled with fiscal policy prescriptions such as taxing the net worth of capital gains from land sale transactions and deforestation. Taxes on land sales would increase the cost of speculating land and stabilize existing farms. Conversely, taxing deforestation should increase the

costs of opening primary forest beyond subsistence levels and control the expansion of extensive forms of land use such as cattle ranching. Of course existing subsidized credits for traditional cattle ranching in Amazonia would have to be reviewed and eliminated.

A policy prescription that is alternative or complementary to taxation would compensate agents for not deforesting. Studies show that the benefits from environmental services may be higher than the returns from cattle ranching (Margulis 2004). However, the transfer mechanisms by which farmers can be compensated for forgone deforestation do not yet exist in practice and political and technical difficulties need to be overcome for implementation at a considerable scale (Landell-Mills and Porras 2002; Scherr et al. 2004).

Third, incentives for the generation and diffusion of appropriate technologies that can compete with existing funds for research based on cattle and exotic monocultures should be encouraged. Furthermore, research for sustainable land use practices have been devised on research stations, but are rarely applied at the scale needed (e.g., selective reduced-impact timber management, agroforestry systems). Appropriate means need to be devised for disseminating research on sustainable land use practices, as well as incorporating them into the cultural contexts in which they are to be implemented. For example, reduced-impact logging practices require highly technical skills and capacity that cannot be adequately assimilated by small rural producers without considerable investments in capacity training. However these efforts should continue, assigning additional funds for the scientific research of alternative land use practices and dissemination of existing experiences.

Fourth, the opening of roads and other large infrastructure development projects in the region currently threaten to expand deforestation and land degradation processes on an unprecedented scale (Laurence 2001; Nepstad et al 2001). Development projects in the region should internalize the associated social and environmental costs and spend these funds on mechanisms to mitigate negative impacts. Zoning of the affected areas must precede the construction of development infrastructure. Furthermore, civil society and local populations must be informed of the impacts and must have participatory mechanisms through which they enforce the complementary activities to mitigate the

negative social and environmental impacts associated with these development projects. International funds for development projects should be conditioned to the above.

A fifth prescription should be to create the mechanisms for stronger local-level governance systems and an equally strong civil society capacity to oversee government actions. Top-down approaches have proven incapable of dealing with the local-level complexity required to appropriately consider the social and environmental costs of enforcing the kinds of policies suggested above. On the other hand, local governance systems can easily be controlled or manipulated by local level interests (e.g., urban elites who speculate with land or timber) if appropriate mechanisms for smallholder farmers to have their interests considered are not in place. NGOs and multinational development agencies need to empower local groups to strengthen their representation in local governance systems while the federal government should secure mechanisms of participation. However, local control and the empowerment of local people does not always inevitably lead to the desired environmental and social outcomes (see Browder 2002 and Brown and Purcell 2005 for Rondônia case studies) which leads us to the next prescription; the need for cross-scale institutional linkages.

The final prescription is the need to insure institutional cooperation across different scales, from central government agencies and across them to the local level state agencies. Cross-scale institutional arrangements will allow defining common objectives and functions for different institutional partners, securing more effective enforcement and efficient use of resources. Furthermore, institutionalizing mechanisms by which different federal agencies (e.g., IBAMA, INCRA, FUNAI) and state level governments interact to design and enforce land use change policies will allow combining the needs of national and international political concerns with the local capacity to learn and respond faster to environmental and social feedback than do centralized agencies.

The implementation of the policies listed above will require much larger funding than is currently allocated to rainforest conservation. This is necessary for the above policies to be viable in both the short and the long term and to secure their enforcement. The current scenario does not hold much promise for additional funds at the scale required, although the ecological value-added tax is a step in the right direction. Another untapped but potential source are the environmental services that the region can offer to

the national and international community such as carbon storage, water and biodiversity protection. Payment-for-Environmental-Services (PES) and other mechanisms have been devised on an experimental scale and some countries such as Costa Rica have implemented them on larger scales. It is imperative that multinational agencies, international donors, NGOs and the state push the agenda to secure rapid implementation. The role of multinational donors is to secure the funds necessary to implement the paradigm change and reverse current trends at the scale required.

The policies reviewed above would considerably reduce deforestation and promote more sustainable land use practices on the existing agricultural frontiers by stabilizing small landholders in deforested areas. It will further discourage further land speculation and unproductive deforestation by reducing existing economic incentives that are accelerating the closing of existing frontiers and the opening of new frontier zones.

Directions for future research

This research should not be thought of as an end in itself. It is but a step towards illustrating the dominant issues surrounding small landholder land use practices in the new post-frontier context that is unfolding. In this evolving context, the household life-cycle theory turned out to have limited statistical power for explaining processes of land use and land cover change. However, it serves as a useful theoretical framework from which to examine the effects of household level factors on land use within the broader range of socioeconomic and biophysical drivers of environmental change. Inconsistencies among household level factors over time and at different scales of analysis suggested important additions to the household life-cycle theory that consider the mediating effects of time and scale on household life-cycle factors. An important next step in Amazonian frontier research will be to explore the linkages between the levels at which different land use change drivers operate, especially the increasing importance of mid-level or regional factors in mediating their impact on the landscape.

This study corroborates post-modern interpretations of frontier processes (e.g., Cleary 1993; Browder and Godfrey 1997; Barbosa 2000; Wood 2002), whereby the Amazon has become a complex, fragmentary landscape, with regions differentially articulated to the national economy and globalization processes, depending on the

predominant type of social and economic organization that historically established itself in the region and how regional processes, such as institutional alliances between local actors, shapes the present socioeconomic and environmental landscape. For example, Rondônia was established as a populist frontier, the result of massive investments to promote the settlement of landless farmers from the Brazilian southeastern region in the Amazon. At roughly the same time, in the Ecuadorian Amazon, the opening of roads for oil exploration stimulated intense migration of colonists from the Andean and coastal regions of Ecuador into the Amazon region. Despite similar initial processes, the emerging socioeconomic and environmental landscape is increasingly differentiated; the Ecuadorian rural landscape continues to attract inter-regional migrants, increasing present population densities, property fragmentation and the predominance of cash-crop agriculture; whereas the Rondônian landscape is currently characterized by intraregional migration, an outflow of population from the original properties and into urban centers and new expanding frontiers and economic activities shifting towards predominantly cattle-raising activities. Although both are characterized by increasing social and environmental costs, the resulting outcomes and the prescriptions to mitigate them could not be more different.

While autarchic households were dominant during the initial colonization processes of the frontier, the post-frontier demands a closer look at the articulation (or lack of articulation) between household level factors and regional and global forces that mediate and shape land use at the farm level. Land use change studies have yet to determine the interaction of these mid-level forces with household and global level factors. Closer examination of the history of the colonization processes should accompany the study of survey research, since it is only through understanding the history of the colonization process that an accurate interpretation of the causal forces of land use change can be addressed. Furthermore, field work surveys should be followed by systematic measurement of important mid-level parameters across study sites (e.g., demographic changes, characteristics of urban centers, intraregional migration patterns, linkages between economic sectors, and between geographical regions, number and type of professionals in agricultural extension services, credit conditions) that can shed light on how mid-level regional processes over time shape land use strategy decisions at the

household level. The increasing importance of regional processes to interpret the post-frontier landscape brings a new set of issues into the picture that are crucial for understanding present day Amazonia, such as; linkages between household structure, gender and internal migration, urban-rural interphase, overlap and coexistence of informal and formal economies, impact of regional development infrastructure on trading networks, formation of elites and the changing role of the state, social learning processes and land use intensification, forms of social capital and the extent to which it helps consolidate the small farmer sector, among others.

The post-frontier setting in the Brazilian Amazon region presents new challenges and opportunities for researchers and practitioners in the areas of conservation and development. The complexity and dynamic nature of frontier processes makes it impossible to devise appropriate recipes for success based on simple solutions. While necessarily important for modeling land use change processes, life-cycle and demographic factors showed limited applications to curbing deforestation and unsustainable land use management practices. Furthermore, the post-frontier scenario appears to become regulated more and more by regional and global forces that suppress the capacity of the household to mediate its own development path (although important exceptions might be possible through Payment-for Environmental-Services schemes). While this could become problematic, as in the present scenario of widespread pasture establishment, it also offers an opportunity for new forms of development. Social organizations and grassroots movements have become more important over time and in the future could play a more significant role as catalyzers of more sustainable land use practices. Additionally, research and policy can increase the chances of promoting more sustainable land use practices, but these are only possible if governance structures and political will are present for their dissemination. In the future, research should attempt to include local farmers as participants of the research process without romanticizing their contribution. Involving them in different aspects of the research process might help in gaining their support for the type of changes required in the field such as supporting regulations and incentives needed to increase the value of the forest remnants, intensify land use practices and promote alternative economic strategies to cattle raising and land speculation. Only a combination of the political will to create the space for environmental

regulations and incentives at the state level, and a strong bottom-up development model created with the local population, will be able to curb the widespread deforestation and land degradation processes taking place in the Amazon region.

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APPENDIX A

Exploring the spatial configuration of property size dynamics

The location and shape of properties were determined by triangulating field work sketches of the properties drawn with the property owner, satellite imagery identification of land cover boundaries and Geographic Positioning System (GPS) coordinate points taken in the field. Property maps were first sketched out with the landowner farmer during the elaboration of the survey in the field. Over a predrawn representation of the original shape of the property at scale, the farmer drew and identified the current dimensions and shape of the lot. This was done for both survey years (1992 and 2002). Additionally, in the sketch, the farmer identified the location and extension of the different land cover classes within the property boundaries. GPS coordinates taken in the field then helped locate the sketched property within a map-based coordinate system. This information is then overlaid on a Landsat satellite image that has been georeferenced and classified to emphasize changes in land use⁶⁷. Because of the different management decisions made in individual households, boundaries of land use classes in the image correspond to the boundaries of individual properties. Triangulating information from the maps drawn with the farmers, GPS coordinates and the boundaries between management land use classes that are visually interpreted from the Landsat satellite images, very accurate maps of property boundaries were obtained for the survey years (1992 and 2002). The GIS coverages then link the boundary layers in both years to the corresponding information from the survey (e.g., owner, size of property). This then served as the basis for analyzing lot fragmentation and expansion processes within the sample studied. In addition to the 1992 and 2002 coverages of properties, different questions in the survey are used to cross reference the analysis of changes in the size of the properties that occurred beyond the boundaries of the sample frame.

⁶⁷ The specific methodology of classification can be found in Wynne et al. 2006.

APPENDIX B

Summary of transformations to produce normal distributions

Original shape	Transformation	New variable (Equation)
Moderate positive skew	Square root	New X = SQRT (X)
Substantial positive skew with value < 0	Logarithm	New X = LG 10 (X) New X = LG 10 (X + C)
Severe positive skew with value < 0	Inverse	New X = 1 / X New X = 1 / (X + C)
Moderate negative skew	Reflect and square root	New X = SQRT (K - X)
Substantial negative skew	Reflect and logarithm	New X = LG 10 (K - X)
Severe negative skew	Reflect and inverse	New X = 1 / (K - X)

X = variable transformed

C = a constant added to each score in order to bring the smallest value to at least 1

K = a constant from which each score is subtracted so that the smallest value equals 1

APPENDIX C

DESCRIPTIVE TABLES

Table C.1 Descriptive statistics and correlations for land use outcomes and explanatory factors, 1992 (n=219) Variables – All study sites (*municipios*)

	Mean	Std. Dev	Correlation with Land Use Class				
			Secondary Growth	Annuals	Perennials	Pasture	Forest
Land Use							
Natural log (ln) of hectares (has) under secondary growth*	2.692	0.3851		0.049	-0.113	-0.018	-0.090*
Ln Annual crops (has)	2.688	0.2626			0.173*	0.232*	0.023
Ln Perennial crops (has)	2.766	0.3660				-0.032	-0.160*
Ln Pasture (has)	3.180	0.5712					0.146*
Forest (has)	48.276	26.81					
Ln deforested area (has) surveys	3.375	0.681	0.263**	0.403**	0.328**	0.793**	0.227**
Percentage deforested surveys	0.441	0.195	0.244**	0.210*	0.017	0.397**	-0.656**
Lot Context							
Ln area of property survey (has)	4.297	0.538	0.236**	0.236**	0.319**	0.507**	0.778**
Sqrt distance to town	111.54	28.34	0.013	-0.043	-0.282**	-0.148*	0.094
Life Cycle							
Years in Rondônia	14.13	4.759	0.067	0.046	0.108	0.080	0.001
Adults (16-65) F1	3.25	1.69	-0.065	0.149*	0.334**	0.070	0.181**
Age of household (hh) head	47.02	12.5	0.050	0.140*	0.072	0.181**	0.094
Dependency ratio F1	0.924	0.840	0.009	-0.076	-0.039	-0.142*	0.052
Demographic variables							
Women F1	1.44	0.852	-0.027	0.146*	0.202**	0.094	0.150*
Children F1	2.34	1.976	-0.003	0.021	0.108	-0.099	0.148*
Number of families	1.76	1.054	0.059	0.364**	0.414**	0.134*	0.031
<i>Aggregados</i>	1.17	2.672	0.124	0.161*	0.143*	0.192*	0.036
Wealth							
Cattle (own)	21.75	26.18	0.002	-0.062	-0.064	0.732**	0.108
Another rural lot	0.14	0.349	-0.048	0.015	0.080	0.173*	0.167*
Urban properties	0.31	0.464	-0.004	-0.147**	-0.061	-0.011	0.049
Markets							
Off-farm income	0.20	0.606	0.013	0.009	0.001	0.058	0.033
Diarias	56.5	119.9	-0.118	0.239**	0.055	0.256**	-0.010
Diarias (y/n)	0.42	0.494	0.036	0.213**	0.130	0.231**	0.134
Percentage of production sold	57.4	29.7	-0.044	0.038	0.316**	0.012	-0.022

* All land use values that have been converted to natural log were added a constant of 10 to eliminate negative values.

* 0.05 significance level

** 0.01 significance level

Table C.2. Descriptive statistics for land use outcomes and explanatory factors, 2002
(n=203/209) Variables – All study sites (*municipios*)

	Mean	Std. Dev	Correlation with Land Use Class				
			Secondary Growth	Annuals	Perennials	Pasture	Forest
Land Use							
Natural log (ln) of hectares (has) under Secondary growth	2.311	0.011		-0.034	0.043	-0.416**	-0.079
Ln Annual crops (has)	2.591	0.305			0.439**	-0.341**	-0.235
Ln Perennial crops (has)	2.968	0.511				-0.478**	0.157*
Ln Pasture (has)	3.736	0.762					0.183**
Ln Forest (has)	3.423	0.778					
Ln deforestation surveys (has)	3.894	0.737	0.196**	0.068	0.210**	0.835**	0.286**
SQRT percentage deforested (surveys)	5.450	2.048	0.188**	0.081	0.164*	-0.223**	0.850**
Size of lot							
Ln Area of property survey (has)	4.292	0.749	0.243**	0.082	0.273**	0.710**	0.670**
Life Cycle							
SQRT (30 - Years on lot)	3.562	1.140	-0.204**	-0.125	-0.095	-0.029	-0.019
Ln (Adults F1 + 1)	2.97	1.673	0.111	0.161*	0.144	-0.009	0.017
Age of household (hh) head	52.2	12.7	0.248**	0.130	0.182*	-0.084	0.125
Ln (Dependency ratio F1 +1)	0.417	0.373	-0.063	0.012	0.037	-0.088	0.069
Demographic variables							
Women (F1)	1.33	0.841	0.118	0.098	0.083	-0.030	-0.044
Women (All)	2.02	1.293	0.114	0.276**	0.352**	0.012	0.054
Children (F1)	1.30	1.502	0.004	0.068	0.078	-0.097	0.095
Children (All)	2.23	2.133	0.059	0.192**	0.281**	-0.005	0.055
Number of families	1.48	1.042	0.169*	0.294**	0.394**	0.052	0.047
Aggregados	0.53	1.184	0.159	0.079	0.268**	0.239**	0.299**
Aggregados (y/n)	0.13	0.340	0.057	-0.042	0.066	0.266**	0.174*
Socioeconomic Context							
Region of birth (1=S, SE; 0= N NE, CW)	0.75	0.434	0.018	0.053	-0.031	0.071	-0.001
Initial wealth	2.81	3.353	-0.044	-0.123	-0.057	0.158*	0.138
Human Capital							
Years in Rondônia	23.0	6.7	0.056	-0.012	0.006	0.012	0.005
Ln Education	1.73	0.48	-0.096	-0.058	-0.089	0.030	-0.061
Social Participation							
Cooperatives	0.09	0.284	0.101	-0.019	-0.049	0.123	0.011
Associations	0.49	0.501	-0.060	0.154*	0.264**	-0.012	-0.024
Syndicates	0.60	0.491	0.091	0.151*	0.297**	-0.016	0.031
Wealth							

Ln (1+Cattle [own])	3.35	1.789	-0.202*	-0.025	-0.199**	0.676**	0.044
Another rural lot	0.37	0.485	0.005	-0.070	0.057	0.535**	0.322**
Wealth index final	7.48	4.02	-0.033	0.095	0.106*	0.354**	0.219**
Urban connections							
Urban properties	0.22	0.418	0.129	-0.191**	-0.121	0.210**	0.151*
Urban families	0.78	0.414	-0.004	0.010	-0.077	0.101	0.013
Market integration							
Off-farm income	0.59	1.009	0.024	0.059	0.058	-0.152*	-0.202**
Off-farm income (y/n)	0.34	0.473	0.070	0.032	0.020	-0.129	-0.082
Diarias	61.91	122.9	0.030	0.118	0.126	0.238**	-0.029
Diarias (y/n)	0.57	0.497	-0.041	0.093	0.161*	0.243**	0.049
Percentage of production sold	70.5	35.2	-0.012	-0.040	-0.160*	-0.184	0.060
Checking	0.34	0.476	-0.072	0.046	0.084	0.227**	0.007
Savings	0.10	0.301	0.046	0.025	-0.156*	0.038	0.137
Credit	0.21	0.411	-0.042	0.239*	0.131	0.072	0.054
Lot context							
Distance to markets	12984.5	7698.8	0.098	-0.184**	-0.085	0.065	0.201*
Fire	0.38	0.487	-0.071	0.026	0.056	0.046	-0.111

* 0.05 significance level

** 0.01 significance level

Table C.3. Descriptive statistics for land use outcomes and explanatory factors, 1992-2002 (n=145) Variables – All study sites

	Mean	Std. Dev	Correlation with Land Use Class				
			Secondary Growth	Annuals	Perennials	Pasture	Forest
Land Use							
Square root (Sqrt) change 02-92 (ch) of hectares (has) under secondary growth	5.228	1.09		0.038	-0.086	-0.166	-0.026
Sqrt ch of has under annual crops	4.712	0.616			0.305**	-0.127	0.077
Sqrt ch of has under perennial crops	5.270	0.910				0.046	-0.079
Ln ch of has under pasture	3.817	0.656					-0.033
Ln ch of has under forest	3.981	0.581					
Ln (ch in area deforested has + 62)	4.489	0.359	0.132	0.158	0.292**	0.741**	-0.065
Change of percent deforested + 30	57.88	22.296	0.052	0.124	0.346**	0.194*	-0.721**
Size of lot							
Ln change area of property has (02-92)	3.242	1.448	-0.043	0.086	0.123	0.635**	0.274*
Life Cycle							
Sqrt (30 -Years on lot (02))	3.013	0.838	-0.007	0.096	0.168*	0.140	0.185*
Ch in adults (02-92) F1 + 10	9.548	2.349	-0.135	-0.059	-0.058	0.050	0.029
Sqrt (32 – ch num adults All)	3.867	0.530	0.010	-0.144	-0.212**	-0.087	-0.105
Ln (Adults F1 02)	0.997	0.486	-0.054	0.035	0.008	-0.031	0.033
Ln (Adults All 02)	1.429	0.568	0.093	0.010	0.024	0.044	-0.052
Age of household head 02	54.83	11.838	0.182*	-0.053	-0.040	-0.122	-0.106
Ch Dependency ratio (02-92) F1 + 4	3.587	1.026	0.086	0.007	-0.005	-0.033	0.101
Inverse ln (8 – (Ch Dependency ratio All + 5))	1.119	0.269	-0.111	-0.034	0.052	0.128	-0.071
1 / (Dependency ratio 02 All + 1)	0.690	0.195	-0.119	-0.050	0.004	0.123	0.022
Demographic variables							
Ln (Women F1 02 + 1)	0.79	0.345	0.017	0.021	-0.002	-0.075	-0.070
Ln (Women All 02 + 1)	1.178	0.474	0.002	0.031	0.034	0.095	-0.001
Sqrt (4 - Change in adult women F1)	2.011	0.311	0.037	0.052	0.050	-0.021	0.034
Sqrt (Men F1 02)	1.197	0.477	-0.160	0.107	0.035	0.060	0.092
Sqrt (Men All 02)	1.530	0.558	0.011	0.017	-0.015	0.101	-0.027
Sqrt (3.1 - Change in adult men F1)	1.831	0.369	0.148	-0.079	0.031	-0.091	-0.075
Ln (Number of families	1.48	1.042	0.072	0.008	0.052	0.131	-0.136

02)							
Change in number of families	-0.11	1.290	0.028	0.208**	0.385**	0.129	-0.063
Socioeconomic Context							
Region of birth (1=S, SE; 0= N NE, CW)	0.7462	0.436	-0.060	-0.069	-0.008	0.099	-0.009
Human Capital							
Sqrt (Years on Rondônia)	4.87	0.493	0.073	-0.138	-0.227*	-0.150	-0.137
Education	3.34	3.296	-0.079	0.119	0.089	0.095	0.178
Social Participation							
Cooperatives	0.09	0.285	-0.054	0.026	0.027	0.092	-0.132
Associations	0.49	0.501	-0.036	0.009	0.175*	-0.020	-0.033
Syndicates	0.60	0.491	0.012	-0.137	0.036	-0.060	-0.017
Wealth							
Ln Cattle (own)	4.969	0.514	-0.247*	-0.016	-0.106	0.561**	0.011
Another rural lot	0.35	0.477	0.073	-0.011	0.021	0.486**	0.248**
Wealth index final	7.48	4.019	0.122	-0.057	-0.053	0.313**	-0.001
Urban connections							
Urban properties	0.22	0.418	0.168	-0.095	-0.080	0.129	0.141
Urban families	0.78	0.414	-0.065	0.117	-0.139	-0.021	0.099
Markets							
Off-farm income (y/n)	0.34	0.473	0.155	-0.058	-0.118	-0.063	-0.061
Diarias	61.91	122.92	0.025	0.141	0.182*	0.236**	0.021
Diarias (y/n)	0.57	0.497	-0.041	0.094	0.072	0.178*	0.033
Change in number of diarias 02-92	23.49	131.232	0.011	0.185*	0.211*	0.044	-0.036
Change in the percentage of production sold	15.76	42.9	0.093	-0.022	0.122	-0.105	0.141
Checking	0.34	0.476	-0.068	0.045	0.066	0.206*	-0.117
Savings	0.10	0.301	0.018	0.071	-0.115	-0.102	0.021
Credit	0.21	0.411	-0.100	0.073	0.031	0.040	-0.012
Lot context							
Ln (Distance to markets)	9.312	0.533	0.088	-0.067	0.108	0.175*	0.023
Fire	0.38	0.487	0.041	0.016	0.093	0.055	0.014

* 0.05 significance level

** 0.01 significance level

Transformations to normalize data set for each of the land cover classes

Change in area of secondary growth vegetation 02-92 (has) = SQRT (27 + ChSec02-92)

Change in annual crops 02-92 (has) = SQRT (15 + ChAnn02-92)

Change in area of perennial crops 02-92 (has) = LN (27 + ChPer02-92)

Change in area of pasture (has) = LN (25 + Ch Past02-92)

Change in area of primary forest (has) = LN (80 + ChFor02-92)

Change in deforestation (has) = LN (62 + ChDef02-92)

Change in percent deforested (has) = 30 + ChPerDef02-92

APPENDIX D

MULTIVARIATE REGRESSION MODELS

Table D1. Multivariate regression models of secondary growth, annual crops, perennial crops, pasture and primary forest.

Independent variables (1992)	Multivariate Regression Models (1992)									
	Ln (Secondary growth +10)		Ln (Annual crops + 10)		Ln (Perennial crops + 10)		Ln (Pasture + 10)		Primary Forest	
	1	2	3	4	5	6	7	8	9	10
Constant	2.567	2.691	1.930***	1.957***	2.056***	2.105***	1.330***	1.189**	-124.9***	-134.9***
Household life cycle										
Ln (Number of families + 1)	-0.025		0.258***		0.384***		-0.087		-7.962*	
Ln (Adults [All] + 1)		-0.071		0.118**		0.190***		-0.006***		-3.324
Ln (Dependents [All] + 1)		0.053		0.041		0.037		-0.028		0.908
Ln (Adult Men [F1] + 1)	-0.132		0.060		0.243***		-0.192*		-0.991	
Ln (Adult Women [F1] + 1)	-0.087		0.015		0.034		0.158		3.254	
Ln (Dependency ratio [F1] + 1)	-0.013		0.009		0.037		-0.090*		3.916*	
Age of household head	0.002	0.002	<0.001	0.001	-0.005**	-0.004*	0.001	0.001	-0.020	-0.103
Sqrt (27 - Years in Rondônia)		-0.038		-0.009		0.036		-0.011		5.755**
Lot context										
Ln (area of all properties [has])	0.102*	0.023	0.057*	0.068**	0.128**	0.173	0.538***	0.534***	38.554***	38.515***
Ln (distance to market [town])	< 0.001	< 0.001	0.001*	0.176	-0.001	-0.002**	-0.004***	-0.003**	0.095*	0.087*
Social Participation										
Mutual help associations (y/n)	-0.051	-0.012	0.006	0.021	0.056	0.103*	-0.084	-0.102	2.768	2.070
Syndicates (y/n)	-0.069	-0.059	-0.048	-0.082*	0.025	-0.029	-0.152*	-0.134	5.415	6.855*
Wealth										
Urban property(ies) (y/n)	-0.039	0.010	-0.059*	-0.049	0.002	-0.010	0.040	-0.002	1.515	1.274
Wealth index - final										
Market integration										
Cooperatives (y/n)	-0.104	-0.010	0.109**	0.110**	-0.110	-0.142*	0.294**	0.244*	-3.194	-3.599
Sqrt (101 - Percentage of production sold)	-0.007	-0.001	0.008	0.006	-0.034***	-0.037***	0.011	0.011	-0.196	-0.519
Hired day laborers (y/n)	0.002	0.010	0.097**	0.110***	0.052	0.046	0.112*	0.092*	-4.865*	-5.693**
R ²	0.028	0.023	0.271	0.256	0.408	0.336	0.359	0.371	0.595	0.572
Adjusted R ²	-0.037	-0.046	0.216	0.205	0.362	0.295	0.315	0.327	0.564	0.548
F ratio	0.431	0.331	4.944***	5.070***	8.956***	8.193***	8.245***	8.453***	18.985***	23.765***

* p < 0.10; ** p < 0.05; *** p < 0.01; Ln = Naperian logarithm; Sqrt = Square root

Table D2. Multivariate regression models at secondary growth, annual crops, perennial crops, pasture and primary forest.

Independent variables (2002)	Multivariate Regression Models (2002)									
	Secondary growth		Annual crops		Perennial crops		Pasture		Primary Forest	
	1	2	3	4	5	6	7	8	9	10
Constant	1.181*	1.127**	2.574***	2.552	2.015**	1.762**	1.919**	1.958**	-0.316	-0.178
Household life cycle										
Ln (Number of families + 1)	0.071		0.228**		0.257**		-0.085		0.108*	
Ln (Adults [All] + 1)		0.090		0.169*		0.364***		-0.123*		-0.117
Ln (Dependents [All] + 1)		0.015		0.083		0.094		-0.047		0.038
Ln (Adult Men [F1] + 1)	0.010		0.165*		0.179**		-0.059		-0.046	
Ln (Adult Women [F1] + 1)	0.147*		0.059		0.049		-0.058		-0.002	
Ln (Dependency ratio [F1]+ 1)	0.010		0.098		0.127		-0.088*		0.058	
Age of household head	0.181*	0.167*	0.090	0.112	0.081	0.079	-0.119**	-0.109*	0.103*	0.091
Sqrt (30.1 - Years on lot)		-0.101		-0.027		0.055		-0.003		0.127*
Lot context										
Ln (Area of property [has])	0.205**	0.201**	0.012	0.009	0.185**	0.186**	0.723***	0.706***	0.723***	0.744***
Ln (Distance to market [town])	0.089	0.120	-0.116	-0.097	-0.053	-0.010	-0.058	-0.076	0.028	0.007
Social Participation										
Mutual help associations (y/n)	-0.093	-0.086	0.091	0.112	0.171**	0.191**	-0.023	-0.037	-0.007	-0.011
Syndicates (y/n)	0.035	0.049	-0.013	-0.009	0.126	0.103	-0.021	-0.017	0.011	0.014
Wealth										
Urban property(ies) (y/n)	0.110	0.089	-0.096	-0.149*	-0.063	-0.088	0.056	0.061	-0.029	-0.016
Wealth index (final)		-0.122		0.072		-0.056		1.622		-0.008
Market integration										
Cooperatives (y/n)	0.091	0.107	-0.010	-0.011	-0.038	-0.030	0.031	0.009	-0.031	-0.427
Sqrt (101 - Percentage of production sold)	-0.011	-0.019	0.051	0.041	-0.195**	-0.255**	0.119**	0.178**	-0.031	-0.028
Hired day laborers (y/n)	-0.076	-0.058	0.078	0.084	0.071	0.108	0.053	0.035	-0.104*	-0.128*
R ²	0.190	0.173	0.184	0.162	0.343	0.364	0.555	0.586	0.482	0.494
Adjusted R ²	0.094	0.089	0.094	0.077	0.270	0.299	0.523	0.544	0.445	0.442
F ratio	1.972**	2.060**	2.040**	1.899**	4.734***	5.636***	17.285***	13.948***	12.905***	9.594***

* p < 0.10; ** p < 0.05; *** p < 0.01 ; Ln = Naperian logarithm; Sqrt = Square root

Table D3. Multivariate regression models (change 2002-1992) using 1992 values as independent variables

Independent variables - 1992	Multivariate Regression Models (Change 2002-1992)									
	Secondary growth		Annual crops		Perennial crops		Pasture		Primary Forest	
	1	2	3	4	5	6	7	8	9	10
Constant	-0.260	0.208	5.924***	5.161***	3.102	3.650**	2.332	1.976	6.370***	5.617***
Household life cycle										
Ln (Number of families + 1)	-0.052		-0.241**		-0.247**		0.084		0.067	
Ln (Adults [All])		0.126		-0.084		-0.048		0.064		-0.021
Ln (Dependents [All] + 1)		-0.092		-0.087		-0.079		0.064		-0.051
Ln (Adult Men [F1] + 1)	0.069		-0.197*		0.119		0.084		-0.006	
Ln (Adult Women [F1] + 1)	0.057		0.112		0.032		-0.058		-0.035	
Ln (Dependency ratio [F1] + 1)	0.029		-0.006		0.111		-0.070		-0.103	
Age of household head	0.024	-0.023	-0.001	-0.078	0.061	0.001	-0.302***	-0.248**	-0.203*	-0.122
Sqrt (30 - Years on Rondônia)		0.053		0.013		0.036		0.057		0.001
Lot context										
Ln (area of all properties [has])	0.118	0.118	0.009	-0.007	-0.101	-0.093	0.126	0.118	-0.207*	-0.185*
Ln (distance to market [town])	0.154	0.155	-0.135	-0.087	0.109	0.117	0.133	0.127	-0.077	-0.060
Social Participation										
Mutual help associations (y/n)	0.054	0.046	0.080	0.044	0.110	0.102	-0.157	-0.127	0.019	0.018
Syndicates (y/n)	0.104	0.117	0.053	0.101	0.101	0.122	0.001	-0.015	-0.040	-0.080
Wealth										
Urban property(ies) (y/n)	0.180*	0.180*	0.058	0.051	0.097	0.111	0.102	0.122	0.118	0.087
Wealth index - final										
Market integration										
Cooperatives (y/n)	-0.021	-0.049	-0.159*	-0.178*	-0.041	-0.079	0.127	0.122	-0.051	-0.061
Sqrt (101 - Percentage of production sold)	0.184*	0.175*	-0.101	-0.089	0.174**	0.161*	-0.046	-0.064	0.012	-0.028
Hired day laborers (y/n)	-0.306	-0.106	-0.137	-0.151	0.020	-0.011	0.131	0.150*	0.134	0.192**
R ²	0.133	0.136	0.159	0.109	0.188	0.137	0.184	0.179	0.120	0.116
Adjusted R ²	0.035	0.046	0.067	0.020	0.100	0.050	0.095	0.097	0.023	0.024
F ratio	1.354	1.518	1.733*	1.221	2.124**	1.581	2.067**	2.182**	1.244	1.268

* p < 0.10; ** p < 0.05; *** p < 0.01

Ln = Naperian logarithm; Sqrt = Square root

Table D4. Multivariate regression models for change (2002-1992) using change as the independent variables

Independent variables – Change 2002-1992	Multivariate Regression Models (Change 2002-1992)									
	Secondary growth		Annual crops		Perennial crops		Pasture		Primary Forest	
	1	2	3	4	5	6	7	8	9	10
Constant	2.799	2.523	4.718***	4.872***	4.226	4.180**	1.964	2.129*	4.498***	5.308***
Household life cycle										
Sqrt (3.1 – change in number of families)	-0.072		-0.190**		-0.289**		-0.030		0.142	
Sqrt (32 – change number of adults all)		-0.026		-0.044		-0.182*		0.045		0.053
Sqrt (6 – change number of dependents All)		-0.070		-0.156		-0.075		0.091		-0.121
Sqrt (3.1 – change adult men [F1])	0.086		-0.136		-0.063		-0.102		-0.152	
Sqrt (4.0 – change adult women [F1])	-0.109		0.126		0.070		0.140		0.074	
Change dependency ratio (F1) + 4	-0.060		-0.011		-0.065		0.031		0.222**	
Age of household head (92)	0.096	0.060	-0.066	-0.091	0.034	0.028	-0.228**	-0.185**	-0.253***	-0.207**
Sqrt (30 - Years on lot [02])	-0.048	-0.039	0.056	0.063	0.062	0.084	-0.049	-0.006	0.151*	0.176*
Lot context										
Ln (change in size of properties [has])	0.085	0.091	0.012	0.030	0.075	0.102	0.354***	0.289***	0.048	0.063
Ln (distance to market [town])	0.171**	0.170*	-0.086	-0.067	0.139*	0.154	0.106	0.058	-0.109	-0.123
Social Participation										
Mutual help associations 92 (y/n)	0.032	0.029	0.045	0.067	0.094	0.116	-0.139	-0.175**	0.012	0.019
Syndicates 92 (y/n)	0.124	0.106	0.102	0.096	0.127	0.134	-0.040	-0.008	-0.018	-0.012
Wealth										
Urban property(ies) 92 (y/n)	0.127	0.127	0.090	0.100	0.127	0.128	0.110	0.061	0.123	0.105
Wealth index final 02	0.070	0.088	0.001	-0.032	-0.104	-0.103	0.079	0.153*	0.001	-0.014
Market integration										
Cooperatives 92 (y/n)	-0.006	0.054	-0.172*	0.040	-0.020	0.001	0.168**	0.076	-0.079	-0.067
Sqrt (101 – Change in percentage of production sold)	-0.186	-0.139	0.093	0.073	-0.129	-0.133	-0.018	0.047	-0.041	-0.021
Hired day laborers 92 (y/n)	-0.118	-0.105	-0.147*	-0.136	-0.028	-0.031	0.085	0.120	0.112	0.115
R ²	0.125	0.114	0.148	0.102	0.204	0.155	0.302	0.262	0.160	0.116

Adjusted R ²	0.023	0.026	0.049	0.013	0.112	0.071	0.214	0.189	0.062	0.029
F ratio	1.226	1.300	1.491	1.150	2.206**	1.852**	3.409***	3.581***	1.640**	1.326

* p < 0.10; ** p < 0.05; *** p < 0.01

Ln = Naperian logarithm; Sqrt = Square root

Table D5. Multivariate regression models for change (2002-1992) using change as the independent variables

Independent variables	Multivariate Regression Models (Change 2002-1992)									
	Secondary growth		Annual crops		Perennial crops		Pasture		Primary Forest	
	1	2	3	4	5	6	7	8	9	10
Constant	5.008*	5.129*	6.199***	7.252***	5.738**	6.533***	1.928	1.365	3.475**	4.575***
Household life cycle										
Sqrt (3.1 – change in number of families)	-0.077		-0.200*		-0.281**		-0.043		0.084	
Sqrt (14 – change number of adults all)		-0.017		-0.109		-0.129		0.024		-0.013
Sqrt (6 – change number of dependents All)		-0.063		-0.169*		-0.072		0.093		-0.155
Sqrt (3.1 – change adult men [F1])	0.098		-0.129		-0.067		-0.082		-0.166	
Sqrt (4.0 – change adult women [F1])	-0.132		0.118		0.066		0.087		0.077	
Change dependency ratio (F1) + 4	-0.056		-0.024		-0.044		0.106		0.231*	
Age of household head (92)	0.013	-0.019	-0.182*	-0.184*	0.007	-0.004	-0.121	-0.092	-0.234*	-0.197*
Sqrt (30 - Years on lot [02])	-0.035	-0.026	0.069	0.090	0.100	0.095	0.058	0.050	0.157	0.188*
Change in household head	0.213*	0.181*	0.282**	0.248***	0.044	0.031	-0.264**	-0.272**	-0.001	0.062
Lot context										
Sqrt (92 percentage deforestation)	-0.203*	-0.232**	-0.216**	-0.276**	-0.204**	-0.259**	0.101	0.100	0.287**	0.329***
Ln (distance to market [town])	0.120	0.1112	-0.150	-0.195*	0.089	-0.056	0.102	0.148	-0.047	-0.074
Social Participation										
Mutual help associations 92 (y/n)	0.025		0.018		0.092		-0.140		0.014	
Syndicates 92 (y/n)	0.116		0.116		0.105		-0.051		0.019	
Wealth										
Urban property(ies) 92 (y/n)	0.099		0.066		0.127		0.078		0.122	
Wealth index final 02	0.122		0.021		-0.098		0.144		0.003	
Market integration										
Cooperatives 92 (y/n)	0.022		-0.129		-0.007		0.067		-0.073	
Sqrt (101 – Change in percentage of production sold)	-0.105	-0.084	0.155	-0.178*	-0.097	-0.074	0.097	0.081	-0.105	-0.088
Hired day laborers 92 (y/n)	-0.067	-0.044	-0.109	-0.099	0.015	-0.001	0.106	0.143	0.069	0.606
R ²	0.200	0.182	0.261	0.209	0.251	0.154	0.264	0.194	0.244	0.201

Adjusted R ²	0.055	0.055	0.126	0.129	0.116	0.074	0.130	0.117	0.107	0.126
F ratio	1.376	1.651	1.940**	2.638**	1.851**	1.925*	1.972**	2.537**	1.775**	2.663**

* p < 0.10; ** p < 0.05; *** p < 0.01

Ln = Naperian logarithm; Sqrt = Square root