ABSTRACT

SAHA, SHUBHAYU. Spatial Externalities: Evidence on Social Interaction, Market Expansion and Mineral Extraction from Brazil and India. (Under the direction of Erin O. Sills).

Various externalities embedded in human-environment interactions need to be accounted to assess the sustainability of environment and development policies. In this dissertation, I examine three such externalities related to – (i) information spillover regarding agricultural technology through social networks; (ii) integration of milk markets on pasture management choices; (iii) public health impacts of iron ore extraction. The land use and health outcomes I examine are of considerable current policy relevance, as (i) and (ii) are inextricably linked with deforestation in the Brazilian Amazon, while (iii) deals with public health impacts of iron ore mining in India.

The analyses is based on a combination of geo-referenced longitudinal household survey data, GIS data on market and road infrastructure, and classified land cover information from satellite images. The spatial information helps operationalize and quantify the externalities examined in each essay - (i) specification of the reference group (both spatial neighbors and members in the social network) that could influence land use decisions of individual farmers; (ii) constructing distance-based measures between location of farmers and all milk plants, based on the assumption that diminishing distances between them over time indicates expansion of the milk market; (iii) distance-based metrics of proximity of households to iron ore mining areas as a proxy for exposure to environmental pollution from mines.

The policy to support extension and dissemination of technology, credit and marketing through agricultural cooperatives is justified on the grounds that collective learning creates a multiplier effect that amplifies the adoption of desirable land use strategies. I find evidence in favor of endogenous social interaction effect, as land use decisions of other members in the social network based on common membership in agricultural cooperatives in the Brazilian Amazon are found to influence choices of individual farmers.

If increased profit from cattle ranching is utilized in intensification of pastures rather than extensification, then policies to support the growth of dairy and beef markets

could reduce the propensity of small farmers to deforest and migrate in the Amazon frontier. Though I find weak evidence in favor that expanded market opportunities encourage farmers to intensify, it has mostly followed extensive deforestation.

While mines create short term employment benefits and long term development in public infrastructure, they also create negative externalities through pollution and environmental degradation. I find that the environmental health impacts of mines increase the incidence and workdays lost due to Acute Respiratory Illness, while the latter is true for Malaria.

Spatial Externalities: Evidence on Social Interaction, Market Expansion and Mineral Extraction from Brazil and India

by
Shubhayu Saha

A dissertation submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the Degree of
Doctor of Philosophy

Forestry

Raleigh, North Carolina

2008

APPROVED BY:

_____	_____
Dr. Subhrendu K. Pattanayak	Dr. Mitch A. Renkow
_____	_____
Dr. Yu-Fai Leung	Dr. Erin O. Sills Chair of Advisory Committee

DEDICATION

To ma, baba, bhai and lutu

BIOGRAPHY

Shubhayu Saha was born in Kolkata, India on June 18, 1975. After completing high school, he attended Presidency College, Kolkata and earned a Bachelor of Science in Economics in 1997. He obtained a Masters degree in Economics from Jawaharlal Nehru University, New Delhi in 1999. Having completed his M.A., Shubhayu worked as a Research Fellow at the Humanities Department in Bengal Engineering College studying the Joint Forest Management initiative in West Bengal, India. In 2001, he moved back to New Delhi to work as a Research Associate at the Indian Statistical Institute on a National Science Foundation research on Poverty and Forest Resource Dependence in the Himalayas. He joined the doctoral program in the Department of Forestry and Environmental Resources at North Carolina State University in 2002. During the doctoral program, he has been part of the National Science Foundation supported research in the State of Rondônia, Brazil and World Bank supported research in Orissa, India. Shubhayu's dissertation combines parts of the research that he did in both these projects. Shubhayu was awarded the Doctoral Dissertation Improvement Grant by the National Science Foundation in 2006. He has been selected as a Prevention Effectiveness Fellow at the Centre for Disease Control (CDC) in Atlanta that he begins from July 1, 2008.

ACKNOWLEDGEMENTS

"…Lately it occurs to me, what a long, strange trip it's been." (Robert Hunter)

I want to thank many who have helped, guided, advised, or just been there with me through this journey. For those who I mention, words will fail to capture my feeling of gratitude, admiration and affection. For those I forget, I hope you will forgive.

I am so fortunate to have had Dr Erin Sills as my mentor. Erin's unerring work ethic, inexhaustible reserves of energy and ability to glean simple solutions to problems continue to amaze me (many times putting me to shame). Dr Subhrendu Pattanayak has been a role-model for me, exemplifying how to conduct applied policy research. Subhrendu's contagious passion to do research that affects lives and livelihoods of people has much influenced my career choices. I have learnt a lot from both, and I look forward to continue working with them in future. I thank Dr Mitch Renkow for his encouragement and counsel, and I will fondly remember our extra-curricular conversations on music. I am indebted to Dr. Jill Caviglia-Harris for not just letting me participate in the research in the Amazon, but being always available for advice.

This journey would have been very tough, perhaps impossible without friends, who have been through similar challenges, have been great sources of comfort and support.

It has been a very emotional few years since I began my doctoral program. My mother lost her battle with cancer, and it has been a week since I received the news of losing my younger brother. At times when challenged, I used to summon strength by imagining how proud they will feel to see me having accomplished this. How I wish they were here. And, without her, this journey would have never begun. I owe a lot to Anuradha, my wife, for her love and belief in me.

TABLE OF CONTENTS

List of Tables..... viii

List of Figures xii

1 Introduction 1

1.1 Thesis motivation 2

1.2 Conceptualizing spatial externalities 6

1.3 Synopsis of three empirical essays 8

2 Impact of Social Interaction on Land Use in the Amazon Frontier 13

2.1 Introduction 14

2.2 Social networks and land use choices of farmers 15

2.3 Estimation of impacts of social interactions on individual outcomes 17

2.4 Description of the study area 22

2.5 Description of the data 25

2.6 Empirical specification and results 31

2.6.1 Impact of association membership – OLS, first difference and fixed effects models 31

2.6.2 Test for social neighborhood - Network autocorrelation model 36

2.6.3 Endogenous interaction effect after controlling for correlated unobservables – Association-specific fixed effects 43

2.7 Conclusion 48

2.8 Appendix 51

3 Improved rural markets, pasture intensification and deforestation – small farmers, milk markets and land use in the Amazon frontier 72

3.1 Introduction 73

3.2 Environmental and economic perspectives on cattle ranching in the Amazon ……. 77
3.3 Growth of markets for cattle products in the Amazon …… 80
3.4 Review of literature on agricultural intensification and the environment .. 83
3.5 Conceptual framework …… 87
3.6 Description of the study area …….. 94
3.7 Description of data …….. 98
3.8 Empirical methods and results on extensification and intensification decisions …….. 105
3.8.1 Seemingly Unrelated Regressions for direct impact of market expansion on extensification and intensification decisions ……. 107
3.8.2 3SLS models of intensification and extensification decisions (endogenous milk price) …….. 109
3.8.3 Fixed effects estimation (endogenous milk price) ……... 113
3.8.4 Dynamic models with lagged price of milk ……. 116
3.9 Impact of intensification on deforestation and migration …… 118
3.10 Conclusion ……. .. 121
3.11 Appendix …….. 123

4 More wealth but poor health? Examining the local health impacts of iron ore mining in India …… 144
4.1 Introduction …….. 143
4.2 Local health consequences of mining ……...148
4.3 Prevention options to mitigate incidence of ARI and malaria …….. 151
4.4 Study area ……..155
4.5 Description of the data ……..158
4.6 Conceptual framework ……..162
4.7 Econometric models for health outcomes ……164

4.7.1 Probit model for incidence of ARI and malaria …… 166
4.7.2 3SLS models for workdays lost due to ARI and malaria …….. 168
4.7.3 Count data models for workdays lost due to ARI and Malaria ……. 170
4.8 Factors affecting use of prevention measures ……... 177
4.9 Conclusion …… 180
4.10 Appendix …….. 182

5 Conclusion …… 199
6 References …… 205
7 GIS Appendix …….. 235
8 Summary and questionnaire for fieldwork supported by Doctoral Dissertation Improvement Grant from the National Science Foundation in 2006…….. 250

LIST OF TABLES

Table 2.1:	Description of farmer associations ……..	55
Table 2.2:	Comparing average profiles of association members and non-members by survey year ..……..	57
Table 2.3:	Comparing members belonging to large (regional) associations with small (local) associations ……	59
Table 2.4:	OLS regression to check association membership effect on percent land in agriculture …..……	61
Table 2.5:	OLS regression to check association membership effect on percent of land devoted to pasture ..……	62
Table 2.6:	OLS regression to check association membership effect on amount of land devoted to agriculture ..……..	63
Table 2.7:	OLS regression to check association membership effect on amount of land devoted to pasture ..……	64
Table 2.8:	Pooled first differenced model for how new membership changes land allocation to agriculture ..……	65
Table 2.9:	Fixed effects estimation of impact of association membership on agricultural land use ..…….	66
Table 2.10:	Impact of social interaction based on percent land devoted to agriculture based on network autocorrelation models ..……	67
Table 2.11:	Impact of social interaction based on percent land devoted to pasture based on network autocorrelation models ……	68
Table 2.12:	Comparing results from the network autocorrelation models for different years ..……...	69
Table 2.13:	Results from association fixed effects estimation of endogenous social interaction effect on percent of land devoted to agriculture ……	70

Table 2.14: Results from association fixed effects estimation of endogenous social interaction effect on amount of land devoted to agriculture ……..... 71

Table 3.1: Change in area in pasture for states in the Legal Amazon 1996-2006 ……. 126
Table 3.2: Change in heads of cattle for states in the Legal Amazon 1990-2006 …….……..... 126
Table 3.3: Change in total cattle population in Rondônia and study region from 1990-2006 …….. 127
Table 3.4: Change in milk cattle population in Rondônia and study region from 1990-2005 …….. 127
Table 3.5: Profile of milk plants collecting milk from farmers living in the Ouro Preto do Oeste region …….. 128
Table 3.6: Reasons cited by farmers for choosing milk plants …… 129
Table 3.7: Types of intensification activities and investment in milk quality reported by farmers …… 130
Table 3.8: Comparing means of variables across time periods …….. 131
Table 3.9: Probit estimation for completeness of labor market (dependent variable: dummy if farmer hired labor): Full sample ….…… 132
Table 3.10: Probit estimation for completeness of labor market (dependent variable: dummy if farmer hired labor): Balanced panel ….……... 133
Table 3.11: Seemingly Unrelated Regression for impact of market expansion on extensification and intensification (Balanced panel) …….. 134
Table 3.12: Seemingly Unrelated Regression for impact of market expansion on extensification and intensification (Reduced panel) ……..… 135
Table 3.13: 3SLS estimation of pooled data with endogenous milk price (balanced panel) …….. 136

Table 3.14: 3SLS estimation of pooled data with endogenous milk price (reduced panel) ……. 138
Table 3.15: Fixed effects estimation for impact of milk price on extensification and intensification (balanced panel) ……. 139
Table 3.16: Fixed effects estimation for impact of milk price on extensification and intensification (reduced panel) …… 140
Table 3.17: Seemingly Unrelated Regression of lagged price of milk on extensification and intensification (balanced panel) ....……. 141
Table 3.18: Seemingly Unrelated Regression of lagged price of milk on extensification and intensification (reduced panel) …….. 142
Table 3.19: Effect of intensification on deforestation, pasture creation and migration ……...…… 143

Table 4.1: Descriptive statistics of household and individual level variable used in the analyses ……..…… 186
Table 4.2: Descriptive statistics of health outcome indicators for the full sample, and the two blocks separately …….…….. 187
Table 4.3: Distribution of health indicators across the villages (villages are arranged in ascending order according to Euclidean distance to mines) ……..…… 188
Table 4.4: Description of health indicators by sub-groups based on mine employment …… 189
Table 4.5: Probit model for incidence of ARI and malaria among individual family members ……... 190
Table 4.6: 3SLS model for workdays lost due to ARI and malaria ...……... 191
Table 4.7: Comparing count models for workdays lost due to ARI ……. 192
Table 4.8: Comparing count models for workdays lost due to Malaria …… 193

Table 4.9: Results from Zero-inflated Negative Binomial model for workdays lost to ARI and Malaria ……194
Table 4.10: Probit models of adoption of preventive measures ……...195

LIST OF FIGURES

Figure 1.1: Sustainable development triad …… 4

Figure 1.2: Nested model of sustainable development ……. 5

Figure 2.1: Ouro Preto do Oeste settlement in Rondonia, Brazil ……. 51

Figure 2.2: Study area indicating spatial data on landcover, towns, roads and farmers included in the survey in 2005 ……. 52

Figure 2.3: Explanation of social proximity based neighborhood …… 53

Figure 2.4: Explanation of physical proximity based neighborhood …… 54

Figure 2.5: Distribution of association members and non-members in the sample in 2005 …….. 56

Figure 3.1: Ouro Preto do Oeste settlement in Rondonia, Brazil ..……... 123

Figure 3.2: Study area indicating spatial data on landcover, towns, roads and farmers included in the survey in 2005 ..…… 124

Figure 3.3: Evolution of milk processing plants in the study area …….. 125

Figure 4.1: Location of the state of Orissa in India …….. 182

Figure 4.2: Keonjhar district in Orissa (highlighted) …… 183

Figure 4.3: Two blocks included in the study – Joda and Keonjhar Sadar …… 184

Figure 4.4: Classified land cover images for the two blocks Joda and Keonjhar Sadar ……. 185

Figure 4.5: Conceptual framework to analyze the impact of mines on health for the population living in close proximity …… 190

Figure 4.6: Poisson, Negative Binomial, Zero-inflated Poisson and Zero-inflated Negative Binomial models with observed distribution of workdays lost due to ARI …… 193

Figure 4.7 : Poisson, Negative Binomial, Zero-inflated Poisson and Zero-inflated Negative Binomial models with observed distribution of workdays lost due to Malaria …….. 195

INTRODUCTION

1.1 Thesis motivation

As a concept, 'sustainable development' (WCED, 1987) poses challenges for the design and implementation of development policy, many of which remain to be adequately understood and addressed. Rural households in developing countries continue to struggle against their narrow margin of survival, lack of access to technologies, vulnerability to natural hazards, and fragility of the ecosystems in which they are concentrated (Sachs, 2004). Pezzey (1992) mentions the problems inherent in operationalizing 'sustainability' at the project level, as system level effects may not be accurately projected by mere aggregation of project appraisals. Yet, the new field of sustainability science seeks to understand the fundamental character of interactions between nature and society, not only through global processes but also in the context of the ecological and social characteristics of particular places and sectors (Kates et. al., 2001). This dissertation contributes to the understanding of local-scale linkages between determinants of human actions and environmental conditions with three essays on two regions that are forest-rich but low-income. At the broad conceptual level, the essays examine specific, policy-relevant connections between the triad of sustainability (market, environment and society): knowledge transfer, land use and public health. Methodologically, the essays combine household survey data with explicit spatial information from satellite images and GIS databases to model the externalities embedded in the relationships between the three elements of sustainability. In this chapter, I first

discuss these common threads across the three empirical essays, and then provide synopses of each.

In spite of various reformulations, the articulation of 'sustainable development' remains highly contested (Giddings et al., 2002). Though the intention here is not an in-depth review of this debate, a quick appraisal of how the conceptualization has changed helps emphasize the complexities in evaluating public policy through the sustainability lens. Figure 1 depicts the classical sustainability diagram (ICLEI, 1996; Munasinghe, 1993) where environment, society and economy are conceived as separate but connected elements, and the area of overlap in the middle is the desired goal for holistic development. Two criticisms that have been put forward against this formulation express concern about (i) how inclusive each of these three elements are, and in specific contexts, how different dimensions of the problem get categorized into these elements and (ii) whether the sectoral distinction inadvertently pushes policy solutions to focus on individual sectors rather than taking into account the complementarities and feedbacks between sectors (Giddings et al., 2002). With respect to the first point, the initial focus under the 'societal' element was on poverty alleviation (UN, 2001) but has subsequently being much more inclusive. The cross-disciplinary engagement of experts in refining the Human Development Index (Stanton, 2007) and explicit inclusion of health indicators as part of social welfare (Schirnding, 2002) highlight this. With respect to the second point, economists have focused primarily on addressing market failure that obscures the

appropriate cost to depreciation of the natural capital and environmental pollution (Jaffe, 2005). The economic instruments designed to rectify these failures have often ignored

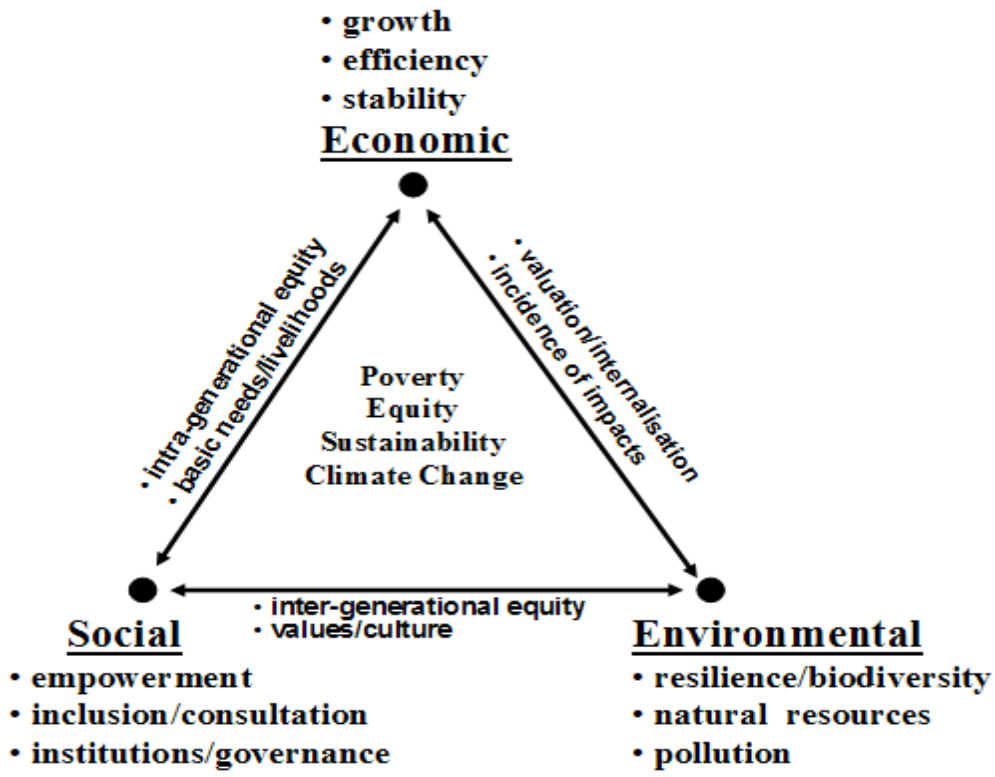


Figure 1.1. Sustainable development triad

non-market mechanisms of exchange and interactions that govern human decisions in regions of relative isolation and incomplete markets (Giddins et al., 2002). In order to capture the feedbacks across these three elements better, Giddins et al. (2002) proposed

an alternative model where the elements were nested within each other rather than functioning as independent entities. They claim that this model (in Figure 2) helps in approaching sustainable development in a more holistic and integrated way. However, even these boundaries are artificial constructs and the boundaries between each element are blurred as humans exist in different capacities and act with different interests in both 'economy' and 'society'.

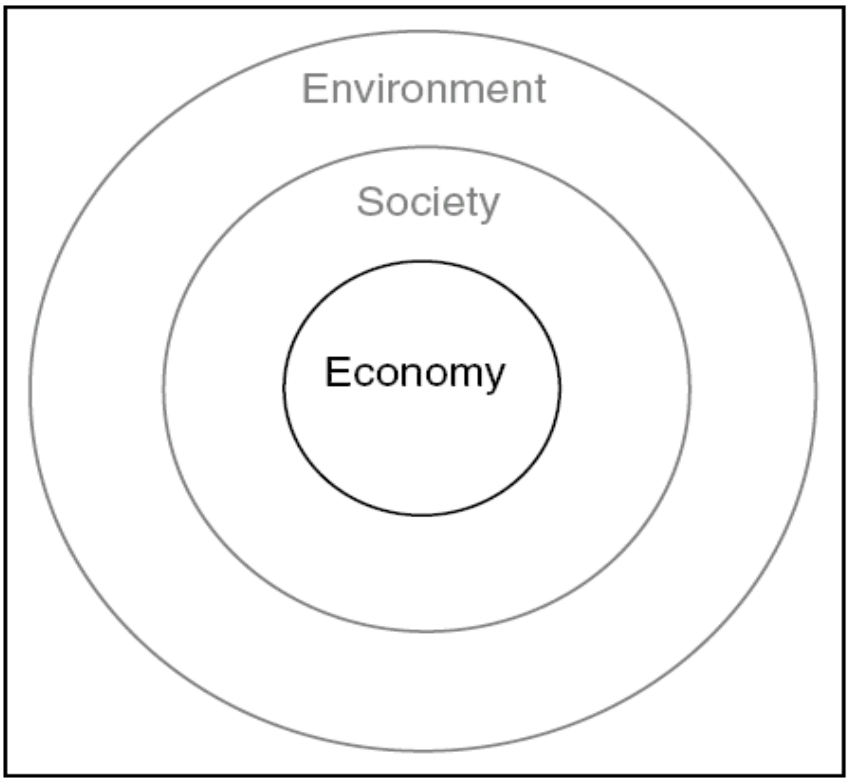


Figure 1.2. Nested model of sustainable development

1.2 Conceptualizing spatial externalities

The nested structure of the integrated model proposed by Giddins et al. implies the existence of multiple feedbacks across elements. This feature emphasizes the complexity of evaluating the welfare and environmental impacts of public policies according to the sustainability criterion. These feedbacks, or action(s) by agent(s) in one of the elements that affect other agent(s) within the same or different elements, are often some form of externality. The three empirical chapters in the dissertation examine three such pathways of externalities – (i) knowledge transfer between farmers that affects household land use choices through social interactions – a network externality; (ii) entry of new firms in an otherwise imperfect product market in rural areas and its impact on household choice of farm management – a pecuniary externality; (iii) extraction of mineral resources that affect welfare outcome of individuals – an environmental externality. The rationale for defining these impacts as externalities arise from the fact that in each instance, the individual outcomes being explained (land use, farm production and health condition) are influenced by factors exogenous to the individual. These outcomes are of considerable current policy relevance, as (i) and (ii) are inextricably linked with deforestation in the Brazilian Amazon, while (iii) deals with the public health impacts of the expanding iron ore sector in India. The definition of externality in (i) relates to recent development in the field of 'social economics' where social interactions and network externalities are treated as forms of non-excludable public good that

influence individual decisions (Dasgupta, 2005). The externality in (ii) arises from expanding production opportunities that a farmer faces with increase in the number of buyers in the local market (Ottoviano and Thisse, 2001). Katz and Shapiro (1985) make a similar argument where demand-side economies are created due to consumption externalities. In the Amazon context, if expanding markets for dairy and beef products lead farmers to create more pasture by clearing more forests on their lot, then it creates a global externality by promoting more deforestation. The externality in (iii) follows from the tradition of environmental economics (Baumol and Oates, 1988), as various forms of pollution from iron ore mining adversely affect human health.

Methodologically, each of the empirical essays utilizes datasets that combine geo-referenced household surveys with spatially explicit GIS and satellite-derived landcover information. The coupled emphasis on spatial dynamics in environmental economics (Anselin, 2002) and the combination of remote sensing and GIS with socio-economic surveys in regional science (Liverman, 1998) allows elaborate contextualization of the linkages between human actions and the bio-physical environment. The spatial information is used to operationalize and quantify the externalities in each essay as (i) neighborhoods of influence (both spatial and social) that could influence land use decisions of individual farmers; (ii) distance-based measures of each farmer's milk market, based on the assumption that diminishing distances between farms and the nearest milk plants represent improvement of the milk market; (iii) distance between

villages and iron ore mining areas as a proxy for exposure to environmental pollution from mines. In each essay, information from classified satellite images is used to derive objective measures of bio-physical variables like land cover change, topography and soil quality that provide more contextual information.

1.3 Synopsis of three empirical essays

Following are synopses of this dissertation's three essays on the (1) influence of social networks within farmer associations on household land use; (2) impact of expansion of milk markets on pasture management; (3) public health impacts of iron ore mining in India.

(1) Economists increasingly recognize the potential influence of social interactions on individual outcomes. In regions like the Amazon frontier with poor public infrastructure, farmer associations can become effective agencies for disseminating management techniques/information and therefore driving land use and frontier development. As members of an association, individual farmers can partake of the repository of the shared knowledge regarding land use alternatives and adapt their choices accordingly.

Using a longitudinal survey of farmers in the state of Rondônia, Brazil, I first examine if participation in associations have any impact on land use choices of farmers.

OLS models with a dummy for association membership show that members allocate more land to crops, but it has no effect on land allocated to pasture.

Having observed the influence of association membership on individual land allocation to crops, I then investigate if social interaction among farmers belonging to the same farmer association leads to similar land use outcomes. Self-reported association membership is used to construct the relevant social network for each farmer. Acknowledging that individual farmers could be influenced by land use choices of physical neighbors as well as neighbors in a farmer's social network, network autocorrelation models similar to spatial autoregressive models are estimated, with a spatial error matrix based on location of farmers on the same secondary road and a social weights matrix based on association membership. Controlling for spatially correlated unobservable factors, social neighborhoods are found to significantly influence individual land use decisions, specifically allocation of land to crops.

Having identified that the association-specific social network significantly affects individual land allocation to agriculture, I then explore for the presence of endogenous social interaction effects among farmers in the association network. The endogenous effect is potentially an important policy lever in the Amazon, as it would amplify the impact of technology adoption or land use decisions by members of farming associations via social interactions. Using association fixed effects model to control for unobserved

association-specific characteristics, growing evidence of endogenous social interaction is found.

(2) Small farmers living on the Amazon frontier in Brazil have attracted the attention of policymakers for two reasons – welfare concerns for a growing rural population and their purported central role in the advance of the deforestation frontier. The common land use trajectory of small farmers in the region begins with mixed cropping on cleared forest land followed by conversion to pasture. In response to declining soil productivity over time, farmers typically resort to extensification, clearing more forest and expanding their pasture. With the right economic and technological conditions, intensification of existing pastures to maintain livestock yields could reduce the pressure for deforestation. The coupled constraints of poor access to credit and product markets are cited as factors that discourage farmers from investing in such intensification strategies. From a policy perspective, it is important to analyze if thicker rural markets for livestock products (e.g.., greater density of milk processing plants) cause farmers to engage in intensive pasture management and reduce deforestation rates.

In this chapter, I investigate smallholders' decisions to intensify pasture management in a region of the western Brazilian Amazon known with relatively good conditions for small farmers (e.g., secure tenure, good soil quality). In particular, I consider whether the expansion of milk processing facilities encouraged pasture

intensification, extensification, or both. I then consider the implications of the pasture management choices for deforestation on the farm and out-migration of family members. I use a three-period panel dataset on land use decisions of farmers in combination with information on concurrent expansion of the dairy industry in the Ouro Preto do Oeste in Rondônia, Brazil. Spatial and temporal information on location of farms and milk plants is used to construct measures of farmers' access to the milk market. Controlling for other determinants of land use, I find that this market access does affect pasture management. The most likely pathway for this impact is that increasing competition among dairies increases milk prices. Indeed, the number of buyers does predict milk prices, and those prices in turn predict both expansion of pasture and income per unit of pasture and per head of cattle. I analyze how milk prices were affected by competition among milk plants and its impact on individual pasture management decisions.

(3) There is a raging public policy debate surrounding expansion and privatization of the mining industry in the state or Orissa in India. On one side of the debate are the proponents of the mining sector who emphasize the short run employment benefits to rural families and the long run benefits in development of local infrastructure like roads and electricity. On the other side of the ring are public interest groups and environmentalist who point out the adverse environmental and social impacts of mining activities.

I reflect on this debate by investigating public health in Keonjhar, the most important iron ore mining region in the state. The analyses combine 600 household interviews conducted across 20 villages along a gradient of proximity to mining areas with secondary spatial information on locations of mines and villages and classified land cover data. For health impacts, self-reported information on incidence and workdays lost due to ARI and malaria are considered in the paper. Exposure to mining is captured by proximity-based variables constructed using GIS data on location of villages and iron ore mines, as well as information on number of days that household members worked in mines.

Estimation results for incidence (Probit) and workdays lost (3SLS and Zero-inflated Negative Binomial) pertaining to ARI and malaria indicate strong association between environmental health (proximity to mines) with ARI-related problems. While incidence of malaria is lower in villages closer to mines, workdays lost due to malaria are higher in villages closer to mines. Families with individuals employed in mines have a higher probability of adopting of improved stoves and bed nets that reduce the burden of ARI and malaria respectively.

Impact of Social Interaction on land use choice in the Amazon

2.1 Introduction

Across the social sciences, researchers have sought to explain how individual behavior is conditioned by the social milieu. Terms such as 'neighborhood effects', 'peer influence' and 'social interaction' reflect attempts to explain how an individual's behavior is affected by actions of others in the reference group to which that individual belongs (Manski, 1993). Following Manski's characterization of social interaction, this paper uses spatially and socially explicit survey data for farmers in the Amazon frontier to empirically estimate how social interaction affects land use decisions. Colonist farmers comprise 83% of the rural population in the Amazon (Pacheco, 2005), and their land use choices are the direct cause of a large proportion of regional deforestation (Laurance, et al., 2001). Thus, there is interest in encouraging these farmers to adopt more environmentally friendly, labor intensive, and sustainable land use practices. The conventional wisdom is that technical and financial assistance for these practices should be delivered through associations that encourage farmers to learn from one another. Over the past decade, the Brazilian government extension agency Emater (Empresa de Assistência Técnica e Extensão Rural) has supported the creation of farmer associations. While there is a qualitative literature and strong (conflicting) opinions about the effectiveness of these associations, there is scant empirical evidence on the existence of information spillovers and associated social multipliers for land use by members of these associations (Sacerdote, 2001).

In most studies of social interaction, specification of the reference group is a critical step towards relating individual actions with some aggregate measure of actions by 'neighbors' or 'peers' in their reference group and thereby inferring social interaction effects. Because of data limitations on social network, neighbors often are defined on the basis of geography (same census tracts or villages) or institutional affiliations (same school, religion or ethnicity). Using geo-referenced locations of farmers and surveys of farmer associations, I construct alternative definitions of social groups to compare the relative influence of spatial (physical) proximity and social affiliations. While I test various social affiliations (e.g., church membership), the key policy lever of interest is membership in farmer associations.

The remainder of this paper is organized as follows. Section 2.2 summarizes the previous literature on the social context of land use decisions. Section 2.3 provides an overview of the empirical literature on estimation of social interaction. Section 2.4 and 2.5 describe the study area and the data. Section 2.6 presents the empirical model and results. Section 2.7 discusses the implications of the results and future extensions.

2.2 Social networks and land use choices of farmers

Farmer organizations have played an important role in demonstration and dissemination of alternative farming practices across the world (Padel, 2001). The

importance of these organizations has been emphasized in the literature on adoption of agricultural technology (Feder, et al., 1985, Rogers, 1995) and is the basis for the Training and Visit Program promoting agricultural innovations (Case, 1992). According to the innovation-diffusion model of Rogers (1995), access to information about an innovation is a key factor determining adoption decisions. Sharing of information regarding profitability of the new technology and experience regarding use of alternative inputs and yields among farmers generate an information cascade that facilitates widespread adoption. Farmers exchange information with their 'neighbors' – defined either by social or geographic commonalities. For example, ethnic affiliations were found to have significant effects on adoption of agricultural technology in Tanzania (Isham, 2002) and Côte D'ivoire (Romani, 2003). People living in the same villages in India were found to influence the allocation of land to HYV crops (Munshi, 2004) and adoption of HYV seeds (Foster and Rosenzweig, 1995). Adoption of sickle among rice-farmers in Indonesia was affected by the number of other adopters in the same district (Case, 1992). In the context of land use in Latin America, local organizations have been found to play an important role in agroforestry promotion in Ecuador (Ramirez, et al., 1992), resource management and agricultural intensification in the Peruvian Andes (Bebbington, 1997), and technology adoption in the Brazilian Amazon (Perz, 2003). Farmers' land use choices have implications for both poverty alleviation and natural resource use. A better understanding of how social interactions condition these choices has critical policy implications.

2.3 Estimation of impacts of social interactions on individual outcomes

Research on social interactions in microeconomics began with the idea that individual choices are a function of some aggregate behavior (Case, 1992). Sociologists also sought to link average neighborhood characteristics to individual outcomes to explain patterns of crime, teenage delinquency and other social problems that plague urban areas (Crane, 1991, Sampson, et al., 2002). These were hypothesized to be sustained by a process of contagion and spread through peer influence (Crane, 1991). Similar peer effects were also identified in educational attainments of students (Henderson, 1978), worker productivity (Jones, 1990) and health outcomes of residents in an area (McIntyre, et al., 1993). Information on the social domain that affects individuals is often unavailable to the researcher. As a result, the early literature often used aggregate level variables to identify social effects on individual-level outcomes, but this is clearly problematic for assessing social interaction effects (Glaeser, et al., 2003). Manski's seminal article (1993) formulated the basic problems in the identification of these interaction effects and much empirical work has followed this typology (Soetevent, 2006).

Following Manski, this study aims to identify and then distinguish the following pathways of social interaction on land use choices of farmers:

(i) Endogenous effect: a farmer allocates more land to a particular use as fellow members of his farmer association do the same.

(ii) Contextual effect: a farmer's allocation of land to a particular use depends on some exogenous characteristics of fellow members of his farmer association.

In order to identify these effects, it is critical to control for:

(iii) Correlated effect: common characteristics of association members (e.g., assets, location, financial assistance from association) that influence similar land use behavior.

Endogenous effects reflect feedbacks between individuals within a group, meaning that small interventions can have larger aggregate impacts through the social multiplier. In contrast, contextual effects do not amplify individual responses to exogenous shocks (Gaviria and Raphael, 2000). Thus, the current focus of much empirical economic research in this area is on testing for the existence of endogenous effects, separate from contextual and correlated effects.

Drawing on this literature, I address three issues (not mutually exclusive) in the empirical analysis: (A) identification of "neighbors" (social and spatial), (B) controlling for correlated unobservable effects (whether due to unobserved spatially correlated biophysical conditions, services offered by farmer associations, or self-selection into the reference group), and (C) separating endogenous from contextual effects.

(A) Identification of neighborhood: Large-scale administrative boundaries (like census tracts in USA) have often been used as the basis for neighborhood definitions (Diez Roux, 2001, Sampson, et al., 2002). In these analyses, the assumption of interactions among all observations living in the same census tract is often questionable. In specific cases, like the analysis of social interactions among farmers in India (Foster and Rosenzweig, 1995, Munshi, 2004), the clustered pattern of residence within a village makes interaction among all living in the village plausible, lending support to physical proximity based definitions of neighborhood. Other definitions of neighborhoods have been more context-specific, such as workers in an assembly room (Jones, 1990); students in the same school (Gaviria and Raphael, 2000) or living in the same dorm (Glaeser, et al., 2003); and countries that have trade relations rather than sharing geographical boundaries (Conley and Ligon, 2002). Romani (2003) has argued for defining the domain of social interaction based on 'social proximity' as more precise and unambiguous than location-based definitions. Accordingly, ethnicity, kinship and religion have been used as the basis for constructing reference peer groups (Bandiera and Rasul, 2006, Luke and Munshi, 2007).

In this study, I use a social-proximity based measure that is also of direct interest as a potential policy lever. The household surveys elicited information on participation in farmer associations. These associations were established with the mandate to provide

farmers with technical and financial assistance primarily for agricultural crops. Members of association attend meetings where they can exchange information on their experiences with different land use systems. Thus, farmers have the opportunity to learn from each others' experiences. I define a farmer's reference group as all farmers in the sample who reported membership in the same association (see figure 2.3 in Appendix for details).

I also have the necessary spatial information to identify physical neighbors. These neighbors may also make similar land use choices because of spatially correlated unobserved factors related to biophysical resources, road quality, etc. Because association membership has some spatial correlation (some associations have spatially clustered membership), it is important to control for physical neighbors when testing for the impact of association "neighbors." Most commonly, Euclidean distances are used to construct spatial weights matrices. In contrast, I assign farmers living on the same secondary roads to the same reference group (see figure 2.4 in Appendix for details). This captures the spatial arrangement of the settlement pattern in the study area and the constraints it imposes on interaction between farmers.

(B) Correlated unobservable effects: as described above, location-specific factors (e.g., biophysical characteristics, presence of traders in specific farm product) may exert a similar influence on all members and thus be confounded with social interaction effects. This problem can also arise from unobservable association-specific factors that affect the

land use of all the members in the association (like a charismatic leader). Endogenous selection into group membership creates a similar problem. Unless these unobservable effects are accounted for in the estimation process, commonalities in land use outcomes would be erroneously attributed to social interaction effects and bias the estimates upward (Moffitt, 2001).

In this study, I first use spatial autoregressive models with location-specific weights matrix in the error to disentangle the effect of social interactions on individual outcome from correlated unobservables. Second, I estimate group specific fixed effects to remove the correlation in land use outcomes arising from unobserved characteristics of the association (Sacerdote, 2001, Soetevent, 2006). Endogeneity could be addressed with suitable instruments that explain membership in associations, but not the land use outcome (Evans, et al., 1992).[1] In the absence of good instruments, I rely on the association fixed effect approach to capture some of the sorting issues that arise in farmers self-selecting into associations (Lee, 2007).

(C) Separating endogenous and contextual effects: This refers to the "reflection problem' identified by Manski (1993), where the feedback between outcomes of individuals who are assumed to interact with each other complicates identification of the exact causal

[1] Another option is to explicitly model the membership decision of agents, where a farmer chooses an association conditional on the choice of other farmers in the first stage to maximize individual benefits. In the second stage, peer effects take effect and land use behavior of other members in the group affect individual choices (Ioannides and Zabel, 2003).

effect. Sacerdote (2001) expands on this problem by claiming that individual-specific exogenous variables (like socio-economic characteristics) could affect not only individual outcomes, but also directly affect the outcomes of other individuals in the group. For a researcher observing final equilibrium outcomes, the challenge lies in adopting suitable strategies to distinguish the endogenous social interaction effect from those being caused by the exogenous variables.

As a strategy to tackle this estimation problem, I use the instrumental variable strategy developed in Gaviria and Raphael (2001). This involved imposing exclusion restrictions on individual-specific variables which are assumed not to have any group-level analogs to influence outcomes of other individuals (Durlauf and Cohen-Cole, 2004). Among the group variables, I exclude individual demographic variables (like age, family size) that only influence individual land use outcome, but should not influence outcomes of other members in the farmer association. However, the group-level variables like productive assets and vehicle ownership are assumed to have exogenous interaction effects.

2.4 Description of the study area

The study area is the colonist settlement of Ouro Preto do Oeste in the state of Rondônia in Western Brazil (Figure 2.1). Designed as a model colonization project by

INCRA (National Institute for Colonization and Agrarian Reform) in 1970, the region (comprising six municipalities) has witnessed an increase in population from 8893 in 1970 to 82,918 in 2007 ((Hogan, 2000) and IBGE)[2]. Waves of migration of colonists, coupled with the paving of the arterial highway (BR-364) and establishment of secondary roads, created pressure on the Amazon frontier (Browder, et al., 2004). As a consequence, similar to other settlements in the Amazon frontier, widespread deforestation ensued. As evident in Figure 2.2, deforested land dominates the landscape with only isolated remnants of the original tropical forest. Analysis of classified Landsat images from 1990 and 2005 show that 64% of the primary forest that existed in 1990 was cleared by 2005. Similar extent of deforestation (more than 70% of total land area) is observed in land cover change analysis conducted at a larger scale in central Rondônia (Alves, et al., 1999).

These colonists have traditionally derived a major portion of their livelihood from cultivating crops and/or maintaining pastures on land obtained from cleared forests (Jones, et al., 1995). Land use choices of these farmers thus leave a critical imprint on the landscape in the frontier. Integration of market networks for dairy products in the region has provided farmers significant financial incentives to allocate land and other capital to cattle husbandry in the region (Caviglia-Harris, 2004). As evidence of this trend, not only

[2] Compiled from UNICAMP report (2000) and Contagem da População 2007, IBGE (Instituto Brasileiro de Geografia e Estatistica)

has there been a six-fold increase in ownership of cattle in 2005 compared to 1990 figures (IBGE)[3], but land devoted to pastures have increased from 41% of the landscape in the study region in 1990 to 66% in 2005. However, many view cattle ranching being not only 'predatory' as it presents incentives to create more pastures by clearing forests ((Fearnside, 1997), (Geist and Lambin, 2002)), but also 'unsustainable' because it leads to decreasing soil fertility, soil compaction and weed invasion (Nepstad, et al., 1991, Serrão and Toledo, 1992) undermining future productivity.

However, in spite of conversion to pasture being a dominant land use strategy of farmers, some have more diversified land use comprising a mix of annual and perennial crops and agroforestry not only in the study region (Caviglia-Harris, 2003, Jones, et al., 1995), but also in other parts of Rondônia (Fujisaka and White, 1998). In this study, these agricultural systems are all included in "agriculture"[4]. Compared to conversion of cleared land to pasture, diversified agriculture is potentially preferable on several counts – (i) revenue from diversified farming is comparable to that from pasture (Lee, et al., 2001), (ii) it may absorb more labor per unit area of land on a sustained basis, thus slowing expansion of the frontier, and (iii) it can contribute to biodiversity (Fujisaka, et

3 Fonte: IBGE - Pesquisa Pecuária Municipal

[4] A more restrictive definition of "agroforestry", which is the combination of woody perennials with annual crops or livestock, is not used in the analysis because information consistent with this definition was not collected in all the surveys. Also, the farmers who reported to have agroforestry systems (a small portion of farmers) also had annual and perennial crops on their plots.

al., 1998), store more carbon in biomass and soils (Naughton-Treves, 2004) and be more compatible with conservation of remnants of primary tropical forests (Perz, 2004).

The study region of Ouro Preto do Oeste was settled less than 40 years ago by colonists from many different states in Brazil, who did not have any significant control over the specific plot that they were assigned. In this situation, farmer associations of various types can form the primary social networks through which farmers learn about alternative forms of land management strategies and share experiences with each other. If this is the case, they may represent a valuable policy lever for effecting land use change. There are over 40 farmer associations in the region, most established in the 1990s. They provide services including cleaning and roasting coffee beans, price negotiation with buyers, access to rice threshers, providing seedlings for native varieties of fruit trees, transporting produce to processing facilities and traders, and application for government credit through local governmental extension agencies. The percent of association membership among farmers in the sample increased from 38% in 1996 to 50% in 2005.

2.5 Description of the data

Household surveys were conducted in the Ouro Preto do Oeste region in 1996, 2000 and 2005. The number of households surveyed in these three years was 171, 172 and 263 respectively. When the panel of households is considered based on the same

household occupying the same lot for the three survey years, the sample shrinks to 129[5]. Detailed information on land use, demography, production and sales of farm products, wealth, access to markets and participation of farmers in social organizations were collected in each year. In an additional survey conducted in 2006, interviews were conducted with the government land extension agency Emater (Empresa de Assistência Técnica e Extensão Rural) to collect information on local farmer associations. Local farmer associations need to register with Emater in order to obtain government credit assigned for agricultural assistance and rural development. Emater offices in each of the municipal towns maintain extensive records on the establishment and operation of each of these local associations. GPS measures were used to collect information on paved and unpaved roads in the entire study area. In conjunction with geo-referenced data on location of farmers who were surveyed, different measures of access to local markets and urban centers can be constructed.

Table 2.1 gives a summary description of the farmer associations. The associations are distributed in each municipality. The associations started being established around early 1990, roughly coinciding with the first round of household survey in the region in 1996. This provides an opportunity to trace the growing influence of associations on household behavior over a 10 year period. Most of the associations

[5] Most of the analysis in this paper is based on the cross-section given the small sample size for the panel. However, some models have been estimated to take advantage of the lagged values to avoid concerns of endogeneity for certain variables.

began with the objective of providing farmers information on farming technology, access to seeds and inputs, facilitate access to government credit and better access to local markets. Most associations focus on crops, and even those that focus on livestock also provide support for crops and agroforestry. The focus on cattle ranching is a recent inclusion in the portfolio of services provided to members, and the impacts of this are weakly observed in the data. From Figure 2.5, note that there is no evidence of spatial clustering among association members. The Spatial Autocorrelation Coefficient to check if only farmers from particular regions in the study area were becoming members in farmer associations is low (0.02) and insignificant. While this inference pertains to farmer associations in general, another possible fact that could confound the empirical estimation stems from the fact that farmers could only choose to become members of particular associations based on the location and services the association provide[6]. The associations in the study area vary in size, the larger ones having a wider catchment area from where farmers join the association. If choices were based only on location of associations, the data on association members would have produced a clustered pattern, where farmers within a particular area would join associations close to their residences. On the other hand, the larger collective pool of knowledge and resources in a bigger association could be more attractive to farmers compared to smaller, more localized one. In Figure 2.5, the indistinguishable pattern among the color codes representing specific association

[6] During fieldwork, we extensively collaborated with the farmer association called Association of Alternative Producers (APA). APA will be considered a regional association according to the definition used in this study (more than 75 members). APA had a relatively larger endowment of resources (vehicles, nurseries and marketing infrastructure) as compared to smaller localized associations.

indicates that proximity to association is not an unambiguous determinant of association membership. We discount the second possibility given the large number of associations in the study area and the fact that 121 members reported to be members of 23 different associations in 2005. Had specific services that farmers prefer been delivered only by the regional (larger) associations, then we should not have observed membership across so many associations. This issue is explored further in Table 3, where association members are classified based on whether they belong to local or regional associations to see if the groups significantly differ.

Table 2.2 describes the variables used in the analysis. For each of the three survey years, the sample is broken down into two groups – members (who reported to participate in any farmer association that year) and non-members (who did not participate in any association in that year).

Land use: Area of land owned has not significantly changed across the two groups between 1996 and 2005. Forest cover has decreased across the groups, consistent with unabated deforestation observed in other parts of the Amazon. Members consistently allocate more land to agroforestry than non-members, though the average number of hectares of land in crops and in agroforestry has declined over time across both the groups. Interestingly, members have significantly increased the conversion of cleared

land to pasture over time, indicating the growing economic importance of livestock in the land use portfolio.

Demography: While the increase in average age of household heads indicates an ageing population in the region, it is not significantly different across members and non-members. Average family size has been significantly higher for members over the years, similar to analysis of household life cycle on agriculture in other parts of the Amazon (Perz, et al., 2006).

Cattle: There has been a marked shift in cattle ownership and management between the two groups over the years. While non-members owned significantly more cattle in 1996, members seem to have caught up with them and have higher average rates of stocking density in 2005. With an average stocking rate of 1.38 heads/hectare in the Amazon (Arima, et al., 2006), the high stocking density for the members could be a result of more active pasture management (indicated by significantly higher use of chemical inputs) or indicative of an unsustainable management regime. Besides the influence on agroforestry choices, social interactions are not found to have significant impact on pasture management of members.

Wealth: Average household cash income has been consistently higher for members, though the contribution of milk to household income has significantly increased for all households. Members have also higher Income from agriculture over the years. Even in case of milk production, members earned higher than non-members as their herd size and pasture management practices have changed over time.

Access to market: There is no significant difference across the two groups with respect to access to markets, defined as distance to either the municipal seat or Ouro Preto. Members both harvest and sell a significantly greater diversity of crops. Note that even though total area in agroforestry has decreased over time, the diversity of crops harvested has increased for both the groups. The decreasing number of crops sold reflects increasing specialization in crops grown for commercial production.

In Table 2.3, similar comparison is made for farmers who reported being member in associations, after having classified the associations as being regional (large) and local (small). Members of larger associations appear to have been significantly different from those in smaller associations in 1996 – they had much larger lots with more forest, a bigger cattle herd and higher income from cattle, more income from agriculture. Interestingly, these differences are not observed in later years indicating that members across associations had similar land use outcomes. Interestingly, in 1996 and 2000, members in larger associations were living significantly closer to Ouro Preto or the closest municipal town. As mentioned before, most of the larger associations are based in these municipal towns that explain the location advantage that members in regional associations may have enjoyed when they joined the associations. But as we observe from the data in 2005, farmers closer to towns reported being part of smaller associations. Thus, association size may not be a critical factor in explaining land use outcomes of association members.

2.6 Empirical specification and results

A sequential empirical strategy is developed in the paper driven by the following questions – (1) Do farmer associations affect individual land use outcomes?; (2) Besides the social network that farmers form through participation in associations, are there other networks that could be influencing land use choices?; (3) Having indentified the association network as the critical one, do we observe endogenous social interaction effects that indicate presence of social learning?

2.6.1 Impact of association membership – OLS, first difference, fixed effects models

To investigate the first question, OLS models are estimated with land use outcomes as the dependent variables and independent variables including a dummy for membership in any association and a set of controls commonly used in the empirical literature on land use change in the tropics. Levels as well percent of land devoted to agriculture and pasture are considered as the dependent variables. The covariates include factors that reflect different theories of land use change – Chayanovian: age, education, family size, asset ownership (Perz at al. 2006, Walker et al. 2002), years living on the lot (Caviglia-Harris, 2003), state of origin (Marquette, 2006); Ricardian – lot size, average slope on the lot, soil characteristics (Vosti, 2002, Reis, 1994); Von thunen: distance to towns and markets (Browder, 2004, Chomitz, 1996) and household specific characteristics like state

from which the farmer migrated and years of living on the lot. The empirical model estimated is the following:

$$y_{it} = \alpha + \beta_1 A_{it} + \beta_2 X_{it} + \varepsilon_{it} \quad (1)$$

Where,

y_{it} = Land use outcome of individual 'i' in association in time 't'

A_{it} = Dummy if individual is a member of a farmer association in time 't'

X_{it} = Set of individual and lot characteristics in time 't'

Looking at Tables 2.4 – 2.7, we observe that the association dummy (β_1) has significant impact on land allocation to agriculture but not on pasture, except for marginal (significance at 15% level) negative impact in 1996. We also observe a growing impact of associations on agriculture choices – the explanatory power of association dummy changes from being insignificant in 1996 to highly significant in 2005 for both levels and percent of land in agriculture. The effect also becomes larger in magnitude in the case of regression on Percent of area in crops, but not in the case of amount of land devoted to crops. The association dummy is insignificant in all of the models for land allocation to pastures. The primary focus of the associations has centered on providing technical and material inputs for agriculture, and thus it is not surprising that membership only has a statistically significant impact on allocation of land to crops. Location of farmers based

on distance to town of Ouro Preto is consistently significant across all the models – farmers allocating more land to agriculture (pasture) the further (closer) they reside from Ouro Preto. Farmers living closer to Ouro Preto live closer to improved road networks that is crucial for transportation of milk produced on the lot. As a result, incentives to convert cleared land to pastures are higher among farmers living closer to Ouro Preto. Wealthier farmers, proxied by value of vehicle ownership, had more pasture on their land compared to agriculture, though this effect was significant only in 2005 and not in the previous periods. Farmers with more family labor tend to allocate more land in agriculture, while the opposite holds for pasture, indicating that agriculture is more labor-intensive.

While the model in Equation (1) was estimated with cross-sectional data for each of the survey years, the next set of estimations considers the panel of farmers to assess whether joining an association affects change in land use. While the sample size for the panel is smaller, the first-differencing controls for individual-specific heterogeneity. Specifically, only those farmers were considered for estimation who were not members of any association in the previous period but became a member in the current period. Instead of using a dummy for association membership as before, a new dummy variable is created to indicate new membership in association. Using the terminology used previously, the estimated model is:

$$y_{it} = \alpha + \beta_1 \tilde{A}_{it} + \beta_2 X_{it} + \eta_i + \varepsilon_{it}$$

$$y_{i,t-1} = \alpha + \beta_2 X_{i,t-1} + \eta_i + \varepsilon_{i,t-1}$$

$$y_{it} - y_{i,t-1} = \beta_1 \tilde{A}_{it} + \beta_2 (X_{it} - X_{i,t-1}) + (\varepsilon_{it} - \varepsilon_{i,t-1}) \quad (2)$$

Where,

$\tilde{A}_{it}$ = Dummy indicating if farmer became an association member between period 't-1' and 't'

η_i = Unobserved farmer-specific characteristics

By differencing the above two equations, the unobserved heterogeneity (η_i) is removed. The impact of new participation in association ($\tilde{A}_{it}$) on the land use outcome is captured by β_1. Results from estimation of equation (2) are presented in Table 2.8. Data from the periods 1996-2000 and 2000-2005 are pooled and only the new association members were considered. As a result, the sample size reduced to 177. Estimates of the model show that new membership increases both amount and percent of land devoted to agriculture, though the effect is significant only between 196 and 2000. Families with more educated household heads and years of residing on the lot devote more land to agriculture. The time-invariant lot specific (soil quality, average slope) and individual characteristics (dummy for migration from South) drop out of the estimation. Note that the time dummy for period 2000-2005 is negative and significant across both the models,

indicating that the effect of participation on agriculture was higher in 1996-2000 than the next period. In the models with the pasture variables as the dependent variables, the effect of new association membership was extremely insignificant.

In another approach, a fixed effects model is estimated using the full panel of 129 farmers for 3 time periods. The farmers in this reduced sample are those who have been staying on the same lot since the first round of surveys in 1996. The estimated model is as follows:

$$y_{it} = \alpha + \beta_1 A_{it} + \beta_2 X_{it} + \eta_i + \varepsilon_{it}$$

$$\bar{y}_i = \alpha + \beta_1 \bar{A}_i + \beta_2 \bar{X}_i + \eta_i + \bar{\varepsilon}_i$$

$$y_{it} - \bar{y}_i = \beta_1 (A_{it} - \bar{A}_i) + \beta_2 (X_{it} - \bar{X}_i) + (\varepsilon_{it} - \bar{\varepsilon}_{ig}) \qquad (3)$$

This estimation helps in assessing the contemporaneous effect of association membership, while controlling for individual heterogeneity (η_i) as in the First-differenced model in (2). Results from estimation of equation (3) are presented in Table 2.9. Association membership is significant and positive in explaining both amount and percent land devoted to agriculture. Contrary to results for equation (2), farmers who have lived on the lot for more years are found to devote less land to agriculture. Farmers reporting to hire labor on their lots allocate more land to agriculture. As before, the individual and lot-specific time-invariant variables drop out of the equation.

Gleaning from the three different forms of estimation, association membership is consistently found to affect individual farmer's decision to allocate more land to agriculture. In the following step, focus is shifted to identify if the social networks of farmers defined on the basis of association membership is most important.

2.6.2 Test for social neighborhood - Network autocorrelation model

An individual farmer can observe and learn from the land use experience of other farmers that one interacts with. These interactions can happen among farmers who are physical neighbors (defined by location of farmers living close by) or social neighbors (farmers belonging to one's social network). In this step, I focus on identification of the network that best explains the land use choice of individual farmers. Based on experience from fieldwork, the physical neighbors for a farmer are defined as those who live on the same secondary road (Figure 2.4 in appendix). Three alternative definitions of social networks are used in the analysis to identify the relative strengths of each in explaining land use choice – common association membership, membership in the same labor unions (sindicato) and membership in the same church.

To test for evidence of interactions among farmers belonging to the same social network, a spatial autoregressive (SAR) structure is specified (Anselin, 2002; LeSage,

1999). The question is whether farmers belonging to an association influence each other by their land use choices. If social interactions do happen to influence individual land use choices, as a researcher, one would observe similar choices made by individuals belonging to the same association. The challenge then is to ensure that the observed similarities in land use are not driven by location-specific unobserved factors (like biophysical characteristics of the parcel, market factors, interaction with farmers who live in close proximity). If the latter holds true, then the observed commonalities in land use outcomes will be erroneously attributed to social interactions.

The specification of the empirical model to test the appropriateness of the social neighborhoods in explaining individual land use choices is as follows:

$$\begin{aligned} Y &= \rho W_s Y + \lambda X + \mu \\ \mu &= \eta W_p \mu + \varphi \\ \varphi &\sim N(0, \sigma^2 I) \end{aligned} \tag{4}$$

Y : specific land use choice made by a farmer (Nx1 dimension vector)

X : vector of exogenous characteristics of farmer i that influence his land use choice (Nxk dimension vector of k regressors)

W_s : weights matrix based on association membership (NxN matrix)[7]

W_p : weights matrix based on physical proximity (NxN matrix)

[7] Similar matrices based on membership in labor unions and churches are also constructed. The results for these models are presented in the tables in the Appendix

φ : Nx1 dimension vector of i.i.d errors with mean 0 and variance $\sigma^2 I$

Such models with a SAR structure called network autocorrelation models have been used in sociology (Leenders, 2002). The procedure to capture social influences in these models depends on the specification of the weights matrix W. Similar to the specification of the weights matrix in spatial econometrics, the element ω_{ij} in the NxN dimensional W_s matrix captures the hypothesized relationship between farmers i and j. So, $\omega_{ij} = 1$ implies that farmers i and j belong to the same associations (similar rationale is used to construct weights matrices based on membership in labor unions and church); $\omega_{ij} = 0$ implies that farmers i and j have no influence on each other because they do not belong to the same social network (same association). By construction, $\omega_{ii} = 0$. Similarly, the W_p matrix is NxN dimensional where $\omega_{ij} = 1$ implies that farmer j lives on the same secondary road that farmer i does. Thus W_s and W_p weight matrices capture possible interaction among farmers working through different mechanisms – the first one through the reported social network of a farmer and the second one based on location. These matrices are then row-standardized assuming that an individual is influenced equally by all the members hypothesized to be neighbors.

The autoregressive coefficient ρ (termed 'social lag') in (4) will indicate the similarity in land use outcomes among farmers belonging to the same farmer association (captured through W_s). It is assumed that such similarity in outcomes is a result of social interaction through which farmers learn and adapt their land use decisions. Instead, if the true process of social influence happens across farmers who are physical neighbors, then the omitted physical influence will be clubbed in the error term. Thus, location-specific common unobservables that could bias the effect of social interaction on land use outcomes are captured with the W_p matrix in the error equation.

The results from estimation of equation 4 are presented in Table 2.10 – 2.12. For each year, the panel (a) in the table of results refers to the model only with the social lag term (W_s) – this indicates if the particular construction of social neighborhood supports the hypothesis of common outcomes among members of the social networks. Panel (b) introduces the spatial error term (W_p) in addition to check if the results are robust after controlling for spatially correlated unobservables.

In Table 2.10, results are reported when the farmer association-based definition of social networks is used. For each time period, the social lag term is positive and highly significant. The results are also robust when the spatial error term is included in the model to control for unobserved location-specific factors. This result indicates that an

individual farmer will increase the percent land devoted to agriculture as other members in the farmer association that he belongs to do the same. The other variables that are most significant across all the cross-sections are age and distance to the town of Ouro Preto. Older farmers have less land in agriculture reflecting the fact that agriculture is more labor-intensive and less conducive for the aged. The fact larger families also tend to devote more land to agriculture support the higher labor input requirements in agriculture. Lots further away from the main town also have more land in agriculture. This may be an indirect result of better transportation networks closer to Ouro Preto, and the incentive farmers have to have more pasture to produce milk that could be shipped relatively easily to milk plants. There is weak evidence for the fact that wealthier farmers, proxied by vehicle ownership, devote less land to agriculture.

In Table 2.11, percent land devoted to pasture is used as the dependent variable to verify if these farmer associations affect agricultural choices of farmers. In none of the models does the social lag term turn out to be significant, indicating that the network of association members do not affect an individual's decision to allocate land to pastures. This supports the preceding analysis where farmer associations were found to consistently influence agricultural choices but not pasture. Among other explanatory variables, older and smaller families tend to devote more land to pasture. Lots that have higher average slope have more pasture, as the terrain is most likely unsuitable for agriculture. Hired labor seem to be used more by farmers who have more land in pasture,

though this effect seems to have weakened over time. Wealthier farmers have more land in pastures, though the causal relationship between the two is ambiguous.

These results support the hypothesis that farmer associations provide a forum for social interaction through which individuals share information about agricultural land use. However, this does not preclude the possibility of other social fora which might serve the same function. Based on field research, the two other social institutions that farmers regularly participate in the study region are labor unions (sindicato) and church. While the primary reason that farmers belong to the labor unions is to ensure that they obtain old age pension provided by the government. Respective municipal towns have the union offices where the farmers are registered and they make occasional visits at these offices to collect money. On the other hand, though most farmers are Christians, they belong to various church denominations. There are different churches along each secondary road and most farmers reported to attend these churches on a regular basis. Recognizing that both of these institutions could also provide opportunities for social interaction, the model in equation 4 is estimated with different specification of the W_s matrix. In these matrices, the element ω_{ij} =1 if farmers i and j are members of the same labor union or attend the same church.

The results reported in Table 2.12 allow comparison of the relevance of the different specifications of the social neighborhoods (W_s). The church-based specification of the social network is insignificant across all specifications. However, the labor union-based social network significantly explains agricultural land use choices of farmers. The social lag term is significant in 2005 and 2000 even after controlling for spatial error. However, close to 95% of the respondents in the sample in 2005 and 2000 report being part of labor unions. All of the farmers who participate in farmer associations are also members of these labor unions. Unlike farmer associations where participation and involvement in association activities are costs that farmers have to bear to take advantage of the services on offer, being part of the labor union is relatively more perfunctory. Also, the mandate of the labor unions is driven by political objectives to protect workers' rights and is vastly different from the objectives of farmer association to actively promote certain kinds of agricultural practices. While the farmer associations could provide instruments for policy interventions, the labor unions are tools of political control. Thus, we focus on the farmer associations in the remaining part of the analysis.

From the preceding analysis, the social network based on association membership was found to land allocation to agriculture. In the next step, we follow Manski's characterization of social interaction and explore for the presence of endogenous social interaction among farmers in the association-specific network.

2.6.3 Endogenous interaction effect after controlling for correlated unobservables – Association-specific fixed effects

Having observed the presence of social influence among members belonging to farmer associations, I now attempt to disentangle the different mechanisms of interaction that may give rise to such common land use outcomes for agriculture among farmers.

Let the following notation denote:

y_i : area in agroforestry devoted by farmer i

x_i : exogenous characteristics of farmer i that influence his agroforestry decision

g : association that farmer i is a member of

N_g : number of members in association g

$\sum_{k=i}^{Ng} y_k = \bar{y}_{-ig}$: average area devoted to agroforestry by all other members in association g excluding farmer i $(i \neq k)$

$\sum_{k=i}^{Ng} x_k = \bar{x}_{-ig}$: average of vector of exogenous characteristics for all members in association g excluding farmer i $(i \neq k)$

Including the correlated group effect, the linear-in-means model in Manski (Manski, 1993) can be written as:

$$y_{ig} = a + \beta \bar{y}_{-ig} + \delta x_{ig} + \theta \bar{x}_{-ig} + \gamma_g + \varepsilon_{ig} \quad (5)$$

In this equation, β indicates the endogenous interaction effect – the effect that decisions made by other members in the association have on the individual; θ denotes contextual effects – how exogenous characteristics of other members in the association affect the individual; δ explains how individual-specific attributes affect land use outcomes; γ_g is an association-specific fixed effect[8].

The method proposed by Lee (Lee, 2007) is used to identify the endogenous and contextual interaction effects in the presence of correlated unobservables. There may be unobserved association-specific characteristics (γ_g) that could potentially cause similar land use outcomes among members in an association. I employ the fixed effect instrumental variable technique identified by Lee, that takes advantage of the variation in group size, to consistently estimate β and θ.

The strategy proposed by Lee is the following:

Averaging both sides of (5) including all the individuals in the group produces

$$\bar{y}_g = a + \beta(\bar{\bar{y}}_{-ig}) + \delta \bar{x}_g + \theta(\bar{\bar{x}}_{-ig}) + \gamma_g + \bar{\varepsilon}_g \quad (6)^{9}$$

[8] Note that aggregate social interaction effect denoted by ρ in equation (4) is broken down into endogenous (β) and contextual (θ) social interaction effect in equation (5)

[9] Note that $\bar{\bar{y}}_{-ig} = \bar{y}_g$

Subtracting (6) from (5) removes the fixed effect term (γ_g) and produces the following equation:

$$y_{ig} - \bar{y}_g = \beta(\bar{y}_{-ig} - \bar{y}_g) + \delta(x_{ig} - \bar{x}_g) + \theta(\bar{x}_{-ig} - \bar{\bar{x}}_{-ig}) + (\varepsilon_{ig} - \bar{\varepsilon}_g) \quad (7)$$

Following algebraic manipulations, Lee (2007) shows that this within equation can also be written as:

$$y_{ig} - \bar{y}_g = -\beta\left[(y_{ig} - \bar{y}_g)/(N_g - 1)\right] + \delta(x_{ig} - \bar{x}_g) + \theta\left[(x_{-ig} - \bar{\bar{x}}_{-ig})/(N_g - 1)\right] + (\varepsilon_{ig} - \bar{\varepsilon}_g) \quad (8)$$

In this process, variation in the size of the group N_g is required for the identification of β and θ. In this study, the number of association members in the sample range from 2 to 11, with an average group size of 4.3. To avoid the 'reflection problem' that arises from the feedback between members in the same group, instrumental variables are used that produces IV estimates of β. For the interpretation of β, notice that the first term in RHS with the coefficient β in (7) measures if other farmers in the group devote more land to agroforestry than the average for the whole group. If there is positive social interaction effect at work, then a farmer will increase his allocation of land in agroforestry in response to similar actions by others in the association. As a result, as $(\bar{y}_{-ig} - \bar{y}_g)$ increases indicating increase in land devoted to agroforestry by others, the endogenous interaction effect should push the individual allocation towards the group mean thus decreasing the LHS $(y_{ig} - \bar{y}_g)$.

Table 2.13 contains the results from the estimation of (8). As mentioned before, identification of the structural parameters in (8) are achieved as the number of members in each of the associations varies. Also exclusion restrictions are used based on the assumption that some farmer characteristics only directly affect individual land use decisions, but do not affect through the contextual interaction effects as captured by group averages. These variables, like family size (indicating available household labor), whether farmer uses chemical inputs like fertilizers, pesticides and herbicides (this should only affect individual productivity, and not have indirect impacts through interaction effects) and soil quality (only affect individual productivity) are used as instruments for average group outcome to address the 'reflection problem'.

The endogenous interaction effect is positive for each of the survey years and highly significant in 2005 and 1996. Comparing the magnitude of coefficients, the influence of association members appear to increase from 1996 to 2005. As mentioned earlier, the average date of establishment of these associations was around 1996. Thus the survey conducted in 1996 coincided with the period when these associations were in their initiation phase and had not begun to create the interaction effects that are being modeled in this paper. However, with time, farmers who participated in associations had greater opportunity to share and learn from each other. Thus I observe a larger influence of members on each other in 2005. Interpreting the coefficient of β in 2005, for every

additional hectare allocated to agriculture by the other group members on an average, the individual farmer increased land in agroforestry by 0.86% in 2005 and 0.91% in 2000.

Younger farmers and larger families are again found to allocate more land to agriculture. Hired labor becomes insignificant and does not explain much of individual agricultural choices. Farmers with greater assets, as measured by the value of vehicles owned, devote less land to agriculture in 2005 and 2000, though the coefficients are not significant. The distance variable is significant as before, indicating that farmers in more remote locations prefer to allocate land and labor to agriculture more. Farmers with poorer soil quality allocated more land to agriculture, probably indicating a higher opportunity cost of converting better quality land to pasture in the region. The contextual effects are largely insignificant in the model. Productive assets owned by members in the group (measured as a composite index of ownership of ploughs, agricultural machinery etc.) could possibly influence land use choices of individuals, but it turns out to be insignificant. The ownership of vehicles by other members of the association is negative and insignificant. If most of the fellow members live far from the lot of a farmer, then it is unlikely that heavy machinery and trucks for transportation of farms produce will be shared between them. However, this effect is more likely to be true in case of regional associations than more localized ones. There is no strong indication towards the existence of contextual effects in land use choices of farmers. In many occasions, farmers who belong to the same association are not physical neighbors. As a result, it will be hard for

them to transport and share heavy agricultural equipments owned by one individual. In such a case, one would think that most of the influence among farmers then will play out though exchange of knowledge spillovers as found for the endogenous interaction effects. Results in Table 2.14, where the dependent variable is amount of land devoted to agriculture, is qualitatively similar. Endogenous interaction effect is positive across all years, but is significant only in 2005.

The effect of social interactions was also tested for land allocated to pasture by farmers. Though the endogenous social interaction term was insignificant across all the model, the productive asset variable was positive and was highly significant. This indicates that the agricultural equipments and machinery are more used y farmer to prepare and maintain the land for pastures rather than agriculture.

2.7 Conclusion

To reduce deforestation by small farmers in the Amazon, one policy option is to disseminate information regarding alternative crop-based agricultural systems that require relatively less cleared land. An implicit assumption in the efforts to promote agricultural technologies through farmer cooperatives is based on the assumption that the rate of adoption of the new technology will be amplified through higher degree of information-sharing among members and better outreach. In this paper, I use reported membership in

farmer associations to empirically identify that indeed association membership influences individual farmers to allocate more land to crop-based agriculture. Controlling for economic factors, such non-market social institutions are found to play an important role in information exchange among farmers in the Amazon frontier.

The first empirical challenge was to identify if the social network of an individual farmer, developed with other farmers in the same association, was an important source of information, as a farmer could also share information with neighbors living close to a farmer's parcel. The spatial autoregressive modeling approach provides an option to control for physical proximity and then identify significant impact of the social network on individual choices.

Having found evidence that such social networks influence agricultural land use of farmers, I then seek evidence in favor of endogenous social interaction that generates the social multiplier. In this paper, I follow Manski's characterization of social interaction effects to examine the influence of social networks on land use choices of farmers. Besides being the first empirical attempt to incorporate social impacts in land use models, I also utilize geographic and social information to refine common approaches of group definitions that are hypothesized to transmit social influence. The significance of the positive endogenous social interaction supports the policy motivations of creating farmers associations – i.e., social multipliers. If the estimated multiplier effects are believable,

small-scale agroforestry promotion, for example, can clearly have wide impacts that could reduce deforestation rates in the Amazon. Importantly, there are welfare implications of providing external support for these associations as poorer farmers tend to benefit more from agroforestry.

The use of spatially autoregressive models also provides an alternative approach to address the problem of correlated unobservables that confounds any analysis of social influence. Unlike applications of SAR models that only utilizes GIS technologies to collect explicit spatial information (e.g., Pattanayak and Butry, 2005), the modification of spatial weights matrices to capture social phenomena suggests new ways for addressing the problem of common unobserved variables.

To address the issues of self-selection into social networks, in future research I will collect detailed spatial and temporal information on association characteristics that will allow to explicitly modeling network selection by farmers.[10] The self-selection parameters can then be included in models of the influence of networks on individual decisions.

[10] In the current paper, self-selection is addressed through association fixed-effects.

2.8 Appendix

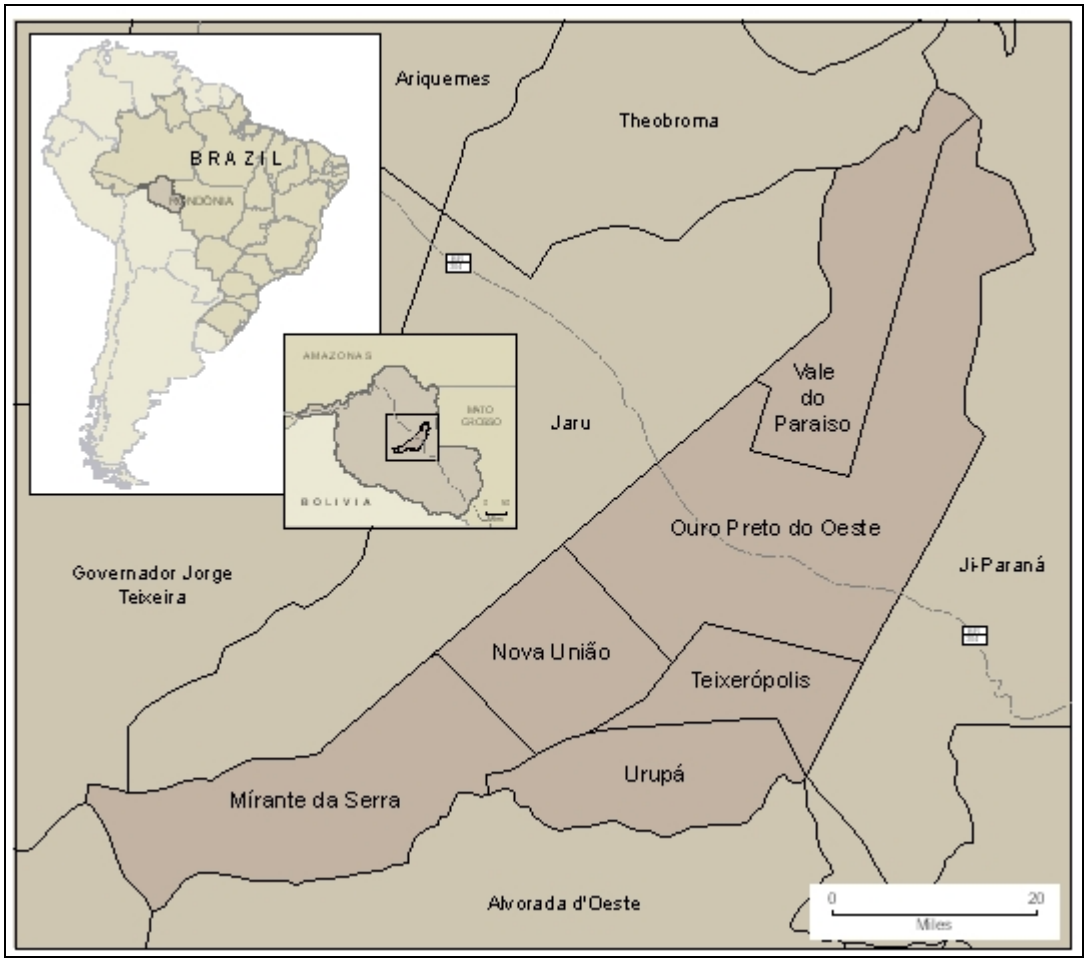


Figure 2.1 Ouro Preto do Oeste settlement in Rondonia, Brazil.
The settlement is comprised of 6 municipalities –
Ouro Preto do Oeste, Vale do Paraíso, Nova União, Teixerópolis, Mirante da Serra and Urupá

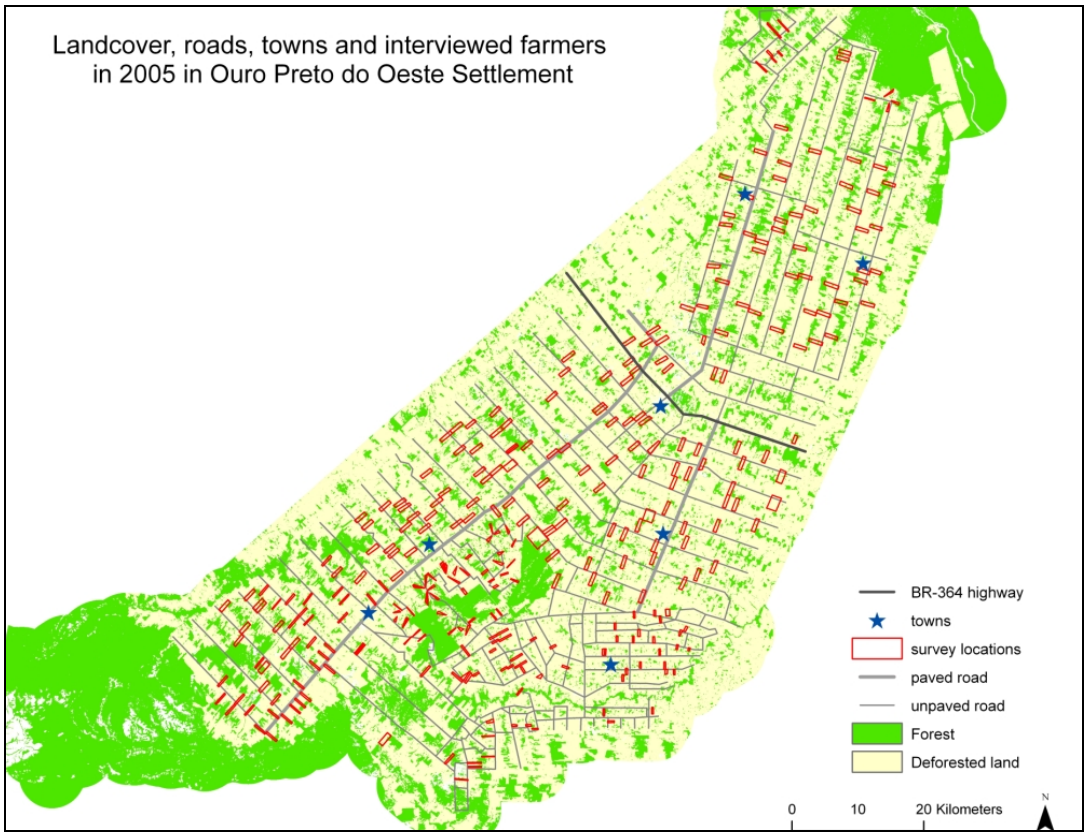


Figure 2.2 Study area indicating spatial data on landcover, towns, roads and farmers included in the survey

farmer 1	Association 1	
farmer 2	Association 2	
farmer 3	Association 1	
farmer 4	Association 1	Association 2
farmer 5		



	farmer 1	farmer 2	farmer 3	farmer 4	farmer 5
farmer 1	0	0	1	1	0
farmer 2	0	0	0	1	0
farmer 3	1	0	0	1	0
farmer 4	1	1	1	0	0
farmer 5	0	0	0	0	0

Figure 2.3 Explanation of social proximity based neighborhood

In the schematic in figures 3A, a hypothetical situation is developed to explain the construction of social neighborhood based on reported in farmer associations. Farmers 1, 3 and 4 in the sample reported being members of association 1. Correspondingly, the matrix reflects the possible social interaction as a function of association membership, where farmer 1 is influenced by land use decisions made by fellow association members, farmer 3 and 4 as captured in cell (1,3) = (1,4) = 1. Similarly, cells (3,1) = (3,4) = 1 and cells (4,1) = (4,3) = 1 indicating the influence of other members on farmer 3 and farmer 4 respectively.

Note that assigning 1 to each cell assumes that each member in the association exerts similar influences on each other. I also construct alternative measures of social influence based on the assumption that farmers who have belonged to an association for a longer period of time can provide qualitatively different information to others as compared to a relatively new member. Thus, the influence is weighted by the years of membership in the association to incorporate this effect.

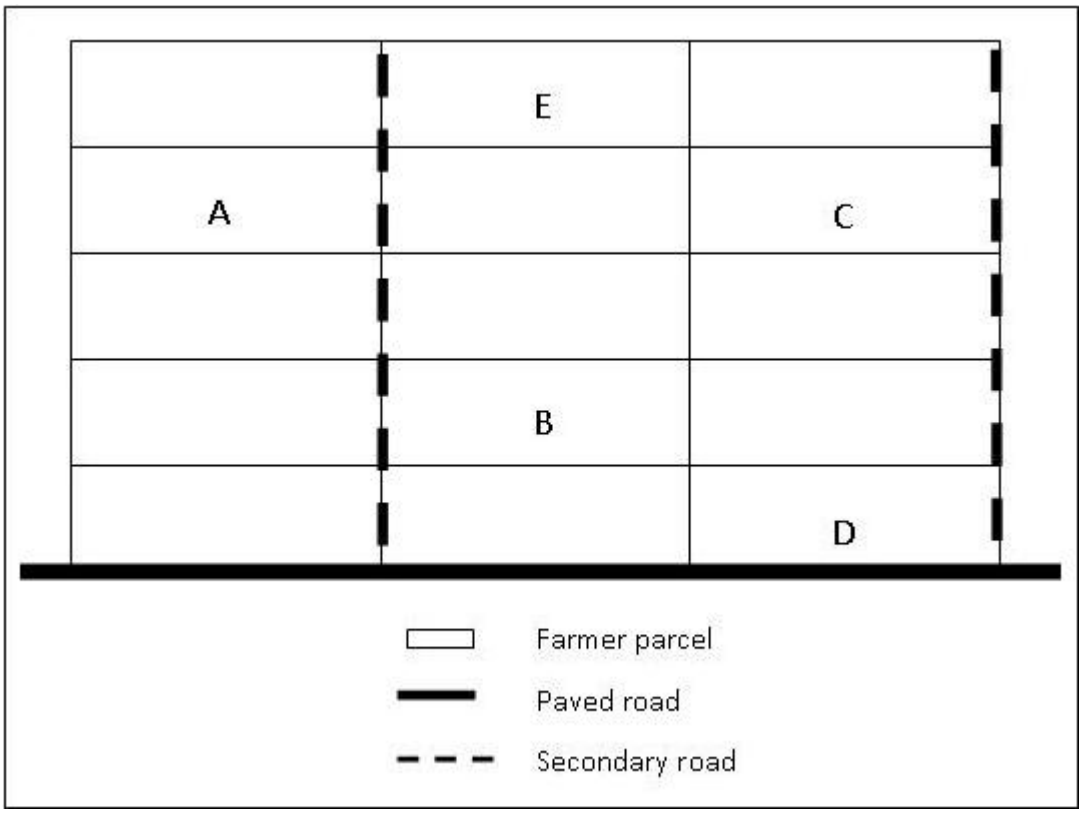


Figure 2.4 Explanation of physical proximity based neighborhood

The schematic in Figure 3B explains definitions of neighborhood based on physical proximity. The settlement pattern in Ouro Preto do Oeste the Amazon has dominantly followed the grid-shaped pattern. Rectangular plots of 100 hectares (2 km by 0.5 km) are distributed along either side of unpaved secondary roads. Experience from fieldwork suggests that frequency of interaction of farmers with others is higher for those living on the same road than the neighbors on the end of their lots. Thus, a farmer living in parcel E may have a higher frequency of social interactions with B as compared to C, even though C is closer to E than B based on measures of Euclidean distance. If based purely on Euclidean distances, E and C may have been assigned the same group reference group even though the spatial distribution of the lots actually lowers the probability of interaction between the two.

Table 2.1 Description of farmer associations

Municipality	Number of associations	Median year of establishment	Average number of members	Focus		
				agriculture	cattle[#]	others
Ouro Preto	15	1996	48	5	6	4
Vale Paraíso	13	1997	28	7	6	
Nova União	14	1996	30	8	5	1
Teixerópolis	7	1997	37	4	3	
Mirante da Serra	13	1999	42	6	5	2
Urupá	13	2001	22	13		
# Associations targeting their assistance to cattle production have been established since 2002-2003						

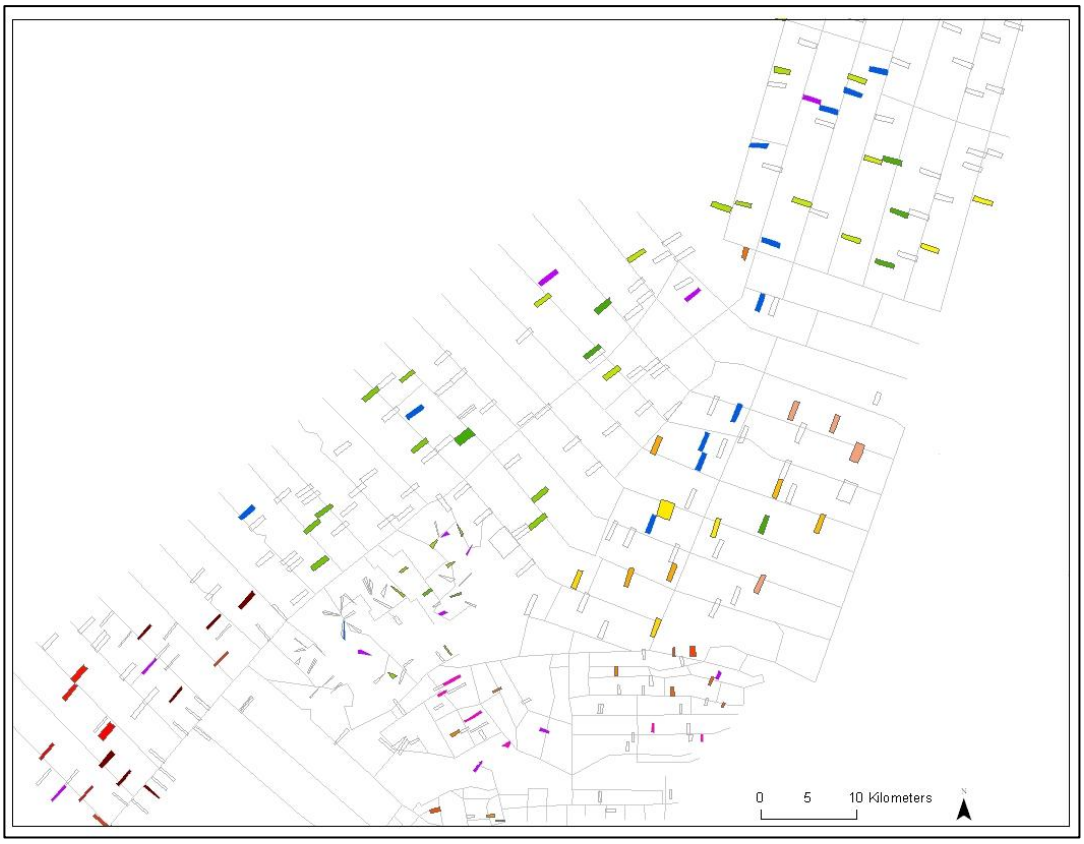


Figure 2.5 Distribution of association members and non-members in the sample in 2005

The association members are color coded. Two points to note from the above graphic – (1) Membership is association is well distributed throughout the study area. The Spatial Autocorrelation Coefficient of association members is low (0.02) and insignificant; (2) If the color codes were clustered, it would have indicated that farmers only become members of associations that are close to where they live. From the absence of the clearly identifiable color pattern in the graphic, some farmers are members of local associations (close to where one lives and smaller in size) as well as regional associations (mostly situated in municipal towns, larger in size with a larger catchment of members).

Table 2.2 Comparing average profiles of association members and non-members by survey year

Average profiles of farmers reporting membership in associations VS non-members by survey year									
	1996			2000			2005		
	member	non-member		member	non-member		member	non-member	
LAND USE									
lot size (hectare)	66	72.4		67.6	61.6		63.4	58.1	
area in agriculture (hectare)	8.9	6.8	*	8.9	5	**	6.5	3.2	**
area in pasture (hectare)	38.5	49.4	**	46.6	44.8		47.5	46.1	
area in forest (hectare)	18.4	16		11.8	11.7		7.2	6.2	
% area in agriculture	17.6	13.6		17.1	12.1	**	14.5	8.4	**
% area in pasture	55.5	63.8		64.9	69.2		70.1	70.6	
% area in forest	26.9	22.6		18	18		13.1	10.5	
DEMOGRAPHY									
average age of hhd heads	47.1	46.1		48.2	49.3		49.7	46	
average education of hhd heads	2.8	2.4		2.7	2.4		3.2	3.3	
family size	9.8	7.9	*	8	7.1		7.8	6.7	*
CATTLE									
size of cattle herd	55	78	**	99	95		89	76	
number of cows for milk	11	17	**	21	19		20	16	
number of cows for meat	43	60	*	79	76		68	60	
number of cattle/ hectare	1.42	1.62		2.43	2.32		2.22	1.68	*
** , * Indicates significant difference between members & non-members in farmer associations at 5% , 10% level									

Table 2.2 (continued).

	1996			2000			2005		
	member	non-member		member	non-member		member	non-member	
WEALTH (constant 2000 reais)									
value of vehicles owned	1659	1241		1780	1557		9463	10883	
income from agriculture	5619	3850		7940	2460	**	4394	1451	**
income from milk	2612	3472		6042	6190		9629	6762	*
income from off-farm sources	2568	1938		3229	3869		4530	3652	
total income	10834	9264		21189	15843	*	23647	16324	**
INPUT USE									
amount paid to hired labor	102	200	*	82	111		796	1063	*
dummy each for use of fertilizer, herbicides, pesticides	1.75	1.21	*	1.84	1.28	**	1.02	0.77	*
MARKET ACCESS									
distance Ouro Preto town (km)	50	47		42	49	*	37	40	
distance to municipal town (km)	16	15		16	15		12	11	
diversity of crops sold	2.3	1.4	*	1.4	1	*	1.3	0.8	**
diversity of crops harvested	6.4	5.2	*	7.4	5.3	*	9.4	7	
number of farmers	47	124		50	122		117	146	
** , * Indicates significant difference between members & non-members in farmer associations at 5% , 10% level									

Table 2.3 Comparing members belonging to large (regional) associations with small (local) associations

Comparing farmers belonging to large (regional) and small (local) associations						
	large association [a]			small association		
	2005	2000	1996	2005	2000	1996
LAND USE						
lot size (in hectares)	76.34	75.06	94.73 *	61.06	61.65	55.08
area in agriculture (hectare)	5.42	9.09	12.50	5.22	9.27	7.56
area in pasture (hectare)	54.60	51.35	48.31	47.65	42.95	34.78
area in forest (hectare)	8.41	14.65	33.38 **	6.54	9.43	12.61
% area in agriculture	15.97	12.57 *	13.73	13.47	20.14	19.07
% area in pasture	66.80	67.55	51.67	73.53	63.41	56.99
% area in forest	14.93	19.96	34.60 *	11.95	16.45	23.94
DEMOGRAPHY						
average age of hhd heads	46.26	50.24	50.19	50.59	47.84	45.93
average education of hhd heads	4.08	2.56	3.00	2.91	2.69	2.69
family size	7.03	8.76	12.46	7.93	7.71	8.82
CATTLE						
size of cattle herd	94.64	101.94	85.23 *	91.24	93.19	42.76
number of cows for milk	19.55	27.41	15.15	19.98	17.26	9.85
number of cows for meat	75.09	74.53	70.08 *	71.26	75.94	32.91
number of cattle/hectare	1.79	2.05	1.74	2.35	2.63	1.30
* indicates significant difference between the average of farmers belonging to large and small associations at the 5% level						

Table 2.3 (continued).

	large association [a]				small association		
	2005	2000	1996		2005	2000	1996
WEALTH (constant 2000 reais)							
value of vehicles owned	7923	2176	3000		5663	1613	1147
income from agriculture	2661	9537	11767	*	2670	7467	3269
income from milk	7104	7519	3259		6326	5252	2365
income from off-farm sources	3055	1924	3949		3468	3802	2040
total income	19049	23147	19090	**	16823	20588	7677
INPUT USE							
amount paid to hired labor	519.49	133.24	196.15		524.51	58.45	66.35
dummy each for use of fertilizer, herbicides and pesticides	0.85	1.82	1.69		1.07	1.90	1.76
MARKET ACCESS							
distance Ouro Preto town (km)	52.59	41.42	36.16	**	46.30	50.97	55.36
distance municipal town (km)	16.13	13.18	12.47	*	16.42	16.99	17.18
diversity of crops sold	1.61 *	1.59	2.23		1.11	1.35	2.29
diversity of crops harvested	9.21	7.29	7.38		9.40	7.71	6.00
Number of observations	33	17	13		88	33	34

a ‘large’ association defined as those with more than 75 members

* indicates significant difference between the average of farmers belonging to large and small associations at the 5% level

Table 2.4 OLS regression to check association membership effect on percent land in agriculture

	Percent of land owned in agriculture								
	2005			2000			1996		
	coeff	*st. err*	*p-val*	*coeff*	*st. err*	*p-val*	*coeff*	*st. err*	*p-val*
Association member (dummy)	**6.32**	1.98	0.00	4.46	3.24	0.17	2.61	2.55	0.31
Average age of Hhd heads	-0.16	0.05	0.00	-0.05	0.11	0.64	-0.09	0.07	0.19
Average education of Hhd heads	-0.38	0.17	0.03	0.50	0.78	0.52	-0.60	0.39	0.12
Family size	**0.62**	0.24	0.01	0.06	0.22	0.80	**0.37**	0.17	0.04
Years living on lot	0.13	0.10	0.20	0.11	0.12	0.36	-0.05	0.16	0.77
Migrated from South (dummy)	0.77	1.64	0.64	5.18	2.31	0.03	-1.73	2.91	0.55
Log of value of vehicles owned	-0.62	0.22	0.01	-0.01	0.34	0.99	0.03	0.27	0.90
Log of distance to Ouro Preto town	3.85	1.19	0.00	8.15	1.99	0.00	7.37	1.90	0.00
Payment for hired labor	0.00	0.00	0.17	0.00	0.00	0.34	0.00	0.00	0.03
Soil suitability	1.31	0.88	0.14	-1.36	1.24	0.28	-1.48	1.43	0.30
Average slope on the lot	-0.19	0.18	0.29	-0.63	0.31	0.04	-0.42	0.23	0.08
constant	-3.88	6.07	0.52	-16.22	12.57	0.20	-3.32	8.65	0.70
N	270			172			171		
Adj R-sq	0.20			0.18			0.19		
Prob > F	0.00			0.00			0.00		
F-val	5.59			3.18			4.14		

Table 2.5 OLS regression to check association membership effect on percent of land devoted to pasture

	Percent of land owned in pasture								
	2005			2000			1996		
	coeff	*st. err*	*p-val*	*coeff*	*st. err*	*p-val*	*coeff*	*st. err*	*p-val*
Association member (dummy)	-4.87	3.61	0.18	-2.99	4.54	0.51	-5.51	3.31	0.10
Average age of Hhd heads	-0.14	0.10	0.13	-0.10	0.16	0.54	-0.03	0.12	0.78
Average education of Hhd heads	-0.42	0.54	0.44	-1.82	1.16	0.12	-0.57	0.70	0.42
Family size	-0.81	0.32	0.01	-0.44	0.36	0.22	-0.17	0.28	0.54
Years living on lot	0.05	0.19	0.78	-0.51	0.23	0.03	-0.45	0.26	0.08
Migrated from South (dummy)	5.14	3.32	0.12	5.65	4.34	0.20	-2.61	4.21	0.54
Log of value of vehicles owned	0.62	0.36	0.08	0.35	0.51	0.49	0.67	0.49	0.18
Log of distance to Ouro Preto town	-9.78	2.17	0.00	-12.17	3.17	0.00	-16.29	2.68	0.00
Payment for hired labor	0.00	0.00	0.11	0.00	0.01	0.65	0.00	0.00	0.00
Soil suitability	-1.49	1.79	0.41	-1.05	2.33	0.65	-4.39	2.29	0.06
Average slope on the lot	0.00	0.40	1.00	0.87	0.47	0.07	-0.02	0.53	0.97
constant	122.37	12.09	0.00	125.44	18.30	0.00	143.12	13.46	0.00
N		270			172			171	
Adj R-sq		0.13			0.18			0.30	
Prob > F		0.00			0.00			0.00	
F-val		4.41			3.22			17.06	

Table 2.6 OLS regression to check association membership effect on amount of land devoted to agriculture

	Amount of land allocated to agriculture (hectares)								
	2005			2000			1996		
	coeff	*st. err*	*p-val*	*coeff*	*st. err*	*p-val*	*coeff*	*st. err*	*p-val*
Association member (dummy)	**1.88**	0.53	0.00	**3.00**	1.29	0.02	1.01	1.17	0.39
Average age of Hhd heads	-0.01	0.02	0.74	-0.03	0.05	0.53	0.02	0.04	0.53
Average education of Hhd heads	-0.11	0.07	0.14	-0.08	0.45	0.86	0.07	0.31	0.83
Family size	**0.43**	0.07	0.00	0.04	0.14	0.79	**0.38**	0.08	0.00
Years living on lot	0.03	0.03	0.43	0.26	0.06	0.00	0.11	0.07	0.11
Migrated from South (dummy)	0.12	0.56	0.83	1.81	1.05	0.09	-0.02	1.21	0.99
Log of value of vehicles owned	0.03	0.06	0.61	-0.04	0.14	0.74	0.15	0.17	0.37
Log of distance to Ouro Preto town	-0.16	0.63	0.80	1.83	1.16	0.12	1.92	0.81	0.02
Payment for hired labor	0.00	0.00	0.77	0.00	0.00	0.43	0.00	0.00	0.08
Soil suitability	0.85	0.36	0.02	0.24	0.60	0.69	-0.32	0.65	0.63
Average slope on the lot	0.00	0.06	0.94	-0.11	0.12	0.37	0.00	0.11	0.98
Lot size	0.00	0.00	0.37	0.02	0.02	0.23	0.02	0.01	0.21
constant	-1.34	2.51	0.59	-5.90	6.89	0.39	-6.37	4.52	0.16
N		270			172			171	
Adj R-sq		0.25			0.18			0.22	
Prob > F		0.00			0.00			0.00	
F-val		10.59			4.24			8.41	

Table 2.7 OLS regression to check association membership effect on amount of land devoted to pasture

	Amount land allocated to pasture (hectares)								
	2005			2000			1996		
	coeff	*st. err*	*p-val*	*coeff*	*st. err*	*p-val*	*coeff*	*st. err*	*p-val*
Association member (dummy)	-1.67	2.55	0.51	-1.23	2.35	0.60	-4.94	3.06	0.11
Average age of Hhd heads	-0.10	0.10	0.31	-0.08	0.10	0.43	-0.06	0.11	0.60
Average education of Hhd heads	-0.23	0.42	0.59	-0.87	0.70	0.22	-0.79	0.61	0.20
Family size	-0.47	0.26	0.08	-0.36	0.24	0.14	-0.15	0.22	0.50
Years living on lot	0.30	0.26	0.24	-0.34	0.19	0.08	-0.51	0.20	0.01
Migrated from South (dummy)	1.47	2.45	0.55	5.40	2.95	0.07	0.27	2.53	0.91
Log of value of vehicles owned	0.45	0.30	0.14	0.01	0.32	0.97	0.50	0.43	0.25
Log of distance to Ouro Preto town	-9.58	4.30	0.03	-4.95	2.39	0.04	-8.10	2.92	0.01
Payment for hired labor	0.00	0.00	0.22	0.00	0.01	0.49	0.00	0.00	0.00
Soil suitability	-0.37	1.53	0.81	-1.89	1.73	0.28	-5.16	2.06	0.01
Average slope on the lot	-0.06	0.29	0.83	0.41	0.28	0.14	-0.34	0.46	0.46
Lot size	0.69	0.12	0.00	0.76	0.04	0.00	0.68	0.07	0.00
constant	41.03	15.51	0.01	26.69	11.62	0.02	53.01	13.75	0.00
N		270			172			171	
Adj R-sq		0.82			0.81			0.84	
Prob > F		0.00			0.00			0.00	
F-val		76.81			70.93			73.87	

Clustered standard errors (by association membership) are reported for all the models in Table 2.4 -2.7.

Table 2.8 Pooled first differenced model for how new membership changes land allocation to agriculture

	Change in percent of land owned in agriculture		
	coeff	*st error*	*p-val*
New association member	1.368	1.361	0.327
Change in average age of hhd head	-0.064	0.020	0.006
Change in education of hhd head	0.207	0.074	0.011
Change in family size	0.048	0.055	0.398
Change in years on lot	0.175	0.048	0.002
Change in log of value of vehicles owned	-0.055	0.056	0.340
Change in payment to hired labor	0.000	0.000	0.090
Time (dummy =1 for 2000-2005)	-5.525	0.470	0.000
Time x new association member	1.027	2.535	0.690
N		177	
Adjusted R-sq		0.04	
F-val		2.37	
Prob > F		0.067	

	Change in amount of land allocated to agriculture		
	coeff	*st error*	*p-val*
New association member	2.308	1.313	0.094
Change in average age of hhd head	-0.027	0.021	0.213
Change in education of hhd head	0.194	0.083	0.029
Change in family size	0.024	0.037	0.526
Change in years on lot	0.205	0.023	0.000
Change in log of value of vehicles owned	0.055	0.023	0.026
Change in payment to hired labor	0.000	0.000	0.760
Time (dummy =1 for 2000-2005)	-3.727	0.299	0.000
Time x new association member	-2.006	1.503	0.197
N		177	
Adjusted R-sq		0.10	
F-val		6.310	
Prob > F		0.006	

These models are estimated using the panel of farmers (N=129). Clustered standard errors (by association membership) are reported. The “new association member” indicates if individual became an association member between the two time periods. Other explanatory variables indicate changes between two time periods. The time dummy = 1 corresponding to 2000-2005 period, and =0 corresponding to 1996-2000. Similar models were run with amount and percent land in pasture as the dependent variable, but new association membership was insignificant.

Table 2.9 Fixed effects estimation of impact of association membership on agricultural land use

	Percent of land owned in agriculture		
	coeff	*st error*	*p-val*
Association membership	2.536	0.804	0.003
Average age of hhd head	-0.095	0.036	0.014
Education of hhd head	-0.026	0.314	0.934
Family size	0.025	0.144	0.864
Years on lot	-0.243	0.062	0.000
Log of value of vehicles owned	-0.007	0.147	0.963
Payment to hired labor	0.000	0.000	0.575
constant	19.117	2.280	0.000
N		387	
Adjusted R-sq		0.08	
F-val		14.01	
Prob > F		0.000	

	Amount land owned allocated to agriculture		
	coeff	*st error*	*p-val*
Association membership	1.327	0.681	0.060
Average age of hhd head	-0.049	0.032	0.145
Education of hhd head	-0.003	0.275	0.993
Family size	0.063	0.060	0.301
Years on lot	-0.087	0.037	0.025
Log of value of vehicles owned	-0.036	0.067	0.595
Payment to hired labor	0.000	0.000	0.145
constant	9.422	2.621	0.001
N		387	
Adjusted R-sq		0.10	
F-val		9.32	
Prob > F		0.000	

Clustered standard errors (by association membership) are reported. Similar models were run with amount and percent land in pasture as the dependent variable, but new association membership was insignificant.

Table 2.10 Impact of social interaction based on percent land devoted to agriculture based on network autocorrelation models

	2005				2000				1996			
	a		*b*		*a*		*b*		*a*		*b*	
	coeff	*p-val*	*coeff*	*p-val*	*coeff*	*p-val*	*coeff*	*p-val*	*coeff*	*p-val*	*coeff*	*p-val*
Average age of Hhd heads	**-0.147**	0.010	**-0.140**	0.017	**-0.125**	0.101	**-0.125**	0.104	**-0.094**	0.183	-0.078	0.265
Average education of Hhd heads	-0.337	0.168	-0.325	0.189	-0.068	0.918	-0.084	0.899	-0.601	0.161	-0.470	0.263
Family size	**0.648**	0.000	**0.652**	0.000	0.074	0.693	0.087	0.642	**0.374**	0.029	**0.423**	0.008
Years living on lot	0.102	0.341	0.102	0.342	0.083	0.522	0.099	0.457	-0.064	0.682	-0.082	0.594
Migrate from South (dummy)	0.307	0.855	0.343	0.838	3.840	0.145	4.232	0.116	-2.152	0.344	-1.057	0.651
Log of value of vehicles owned	**-0.517**	0.005	**-0.510**	0.006	-0.160	0.549	-0.170	0.526	0.027	0.920	0.015	0.953
Log of distance to Ouro Preto	**2.944**	0.003	**2.819**	0.006	**5.841**	0.000	**5.551**	0.000	**6.496**	0.000	**5.294**	0.000
Payment for hired labor	0.000	0.441	0.000	0.413	-0.005	0.262	-0.005	0.275	-0.001	0.212	-0.001	0.258
Soil suitability	1.569	0.144	1.571	0.149	-1.408	0.327	-1.279	0.389	-1.340	0.320	-0.677	0.641
Average slope on the lot	-0.194	0.354	-0.190	0.370	**-0.678**	0.023	**-0.622**	0.049	-0.386	0.168	-0.196	0.510
Social lag (association membership)	**0.255**	0.000	**0.249**	0.000	**0.285**	0.001	**0.275**	0.001	**0.221**	0.015	**0.185**	0.047
Spatial error (living on same secondary road)			0.063	0.467			0.071	0.494			0.217	0.026
N	270		270		172		172		171		171	
Adjusted R-sq	0.12		0.11		0.11		0.09		0.13		0.08	
Log likelihood	-1047		-1047		-683.1		-682.9		-665.6		-662.7	
AIC	2118		2119		1390		1392		1354		1351	

Table 2.11 Impact of social interaction based on percent land devoted to pasture based on network autocorrelation models

	2005				2000				1996			
	a		*b*		*a*		*b*		*a*		*b*	
	coeff	*p-val*	*coeff*	*p-val*	*coeff*	*p-val*	*coeff*	*p-val*	*coeff*	*p-val*	*coeff*	*p-val*
Average age of Hhd heads	**0.243**	0.040	0.191	0.117	**0.539**	0.000	**0.551**	0.000	**0.642**	0.000	**0.311**	0.034
Average education of Hhd heads	0.635	0.206	0.473	0.363	1.744	0.157	1.787	0.147	1.225	0.150	0.288	0.708
Family size	-0.474	0.146	-0.522	0.107	-0.412	0.246	-0.409	0.253	-0.251	0.461	-0.353	0.188
Years living on lot	**0.721**	0.001	0.619	0.007	-0.172	0.485	-0.158	0.523	0.290	0.352	-0.005	0.985
Migrate from South (dummy)	**8.834**	0.010	8.989	0.008	**12.391**	0.012	**13.135**	0.013	**11.169**	0.013	-1.192	0.801
Log of value of vehicles owned	**1.127**	0.003	1.057	0.006	**1.008**	0.046	**1.024**	0.043	**1.281**	0.015	0.755	0.101
Log of distance to Ouro Preto	**6.303**	0.002	**7.860**	0.001	3.571	0.149	3.146	0.234	**4.849**	0.034	**11.007**	0.000
Payment for hired labor	0.000	0.815	0.000	0.991	**0.018**	0.028	**0.018**	0.026	0.002	0.282	0.003	0.168
Soil suitability	1.574	0.473	1.848	0.413	1.150	0.671	1.056	0.692	-2.669	0.322	0.479	0.865
Average slope on the lot	**0.846**	0.049	0.714	0.108	**1.679**	0.003	**1.722**	0.002	0.567	0.304	0.660	0.203
Social lag (association membership)	-0.026	0.511	-0.031	0.438	0.019	0.740	0.022	0.714	-0.125	0.082	-0.076	0.229
Spatial error (living on same secondary road)			0.161	0.073			-0.049	0.709			**0.487**	0.000
N	270		270		172		172		171		171	
Adjusted R-sq	0.10		0.08		0.10		0.10		0.1306		0.022	
Log likelihood	-1240		-1238		-791		-790.9		-781.2		.4	
AIC	2503		2502		1606		1608		1586		1571	

Table 2.12 Comparing results from the network autocorrelation models for different years

Percent of land owned in agriculture												
	2005				2000				1996			
	a		*b*		*a*		*b*		*a*		*b*	
	coeff	*p-val*	*coeff*	*p-val*	*coeff*	*p-val*	*coeff*	*p-val*	*coeff*	*p-val*	*coeff*	*p-val*
Social lag (labor union membership)	**0.33**	0.00	**0.33**	0.03	**0.42**	0.00	**0.42**	0.00	0.04	0.75	-0.02	0.86
Spatial error			0.09	0.26			-0.01	0.96			**0.26**	0.01
Social lag (church membership)	0.16	0.11	0.13	0.19	0.25	0.21	0.24	0.31	0.08	0.35	0.04	0.66
Spatial error			0.08	0.34			0.02	0.87			**0.25**	0.01
Percent of land owned in pasture												
	2005				2000				1996			
Social lag (labor union membership)	-0.01	0.87	-0.01	0.81	-0.07	0.21	-0.07	0.22	0.08	0.21	0.05	0.43
Spatial error			**0.16**	0.08			-0.03	0.84			**0.48**	0.00
Social lag (church membership)	0.06	0.27	0.05	0.40	0.02	0.71	0.02	0.68	0.13	0.04	0.07	0.19
Spatial error			0.14	0.12			-0.05	0.70			**0.47**	0.00

Each of these models is estimated with the same set of covariates as in Table 10 & 11. The social weights matrix (indicated by 'social lag' denote alternate definitions of neighborhood based on common membership in labor union (sindicato) and church. The weights matrix used in spatial error term is the same one constructed on the basis of farmers living on the same secondary road.

Table 2.13 Results from association fixed effects estimation of endogenous social interaction effect on percent of land devoted to agriculture

	2005			2000			1996		
	coeff	*st error*	*p-val*	*coeff*	*st error*	*p-val*	*coeff*	*st error*	*p-val*
Endogenous interaction effect	**0.860**	0.323	0.008	**0.908**	0.473	0.057	1.214	17.854	0.946
Family size	0.506	0.146	0.001	0.136	0.186	0.467	0.368	0.165	0.027
Average age of hhd heads	-0.132	0.044	0.003	-0.089	0.071	0.210	-0.100	0.066	0.135
Average education of hhd heads	-0.177	0.202	0.382	0.185	0.620	0.766	-0.445	0.444	0.318
Payment to hired labor	0.000	0.000	0.308	-0.004	0.004	0.348	-0.002	0.001	0.125
Productive assets	3.755	3.912	0.338	-1.329	4.923	0.788	-2.942	5.066	0.562
Log of value of vehicles owned	-0.344	0.179	0.056	-0.119	0.279	0.669	0.221	0.328	0.501
Log of distance to Ouro Preto	2.594	0.872	0.003	5.652	1.238	<.0001	6.159	1.173	<.0001
Average slope on lot	-0.181	0.182	0.323	-0.526	0.284	0.065	-0.322	0.265	0.226
Soil suitability	2.098	0.985	0.034	-0.832	1.407	0.555	-1.758	1.388	0.207
Productive assets (group)	-1.901	10.286	0.854	26.371	40.304	0.514	38.254	37.174	0.305
Log of value of vehicles owned (group)	0.347	0.720	0.631	-1.559	1.337	0.245	-1.791	1.539	0.246
N		270			172			171	
Adjusted R-sq		0.419			0.465			0.544	
F-val		17.26			13.48			18.030	
Pr > F		<0.001			<0.001			<0.001	

Clustered standard errors by association membership are reported.
Instruments used in the first stage regression are: group level variables for family size, use of fertilizer and average slope.
Productive assets (group) and log of vehicle value (group) indicate contextual interaction effects.

Table 2.14 Results from association fixed effects estimation of endogenous social interaction effect on amount of land devoted to agriculture

	2005			2000			1996		
	coeff	*st error*	*p-val*	*coeff*	*st error*	*p-val*	*coeff*	*st error*	*p-val*
Endogenous interaction effect	**0.752**	0.303	0.014	0.845	0.567	0.138	2.382	11.432	0.835
Family size	0.377	0.060	<.0001	0.067	0.092	0.468	0.364	0.075	<.0001
Average age of hhd heads	-0.015	0.018	0.395	0.005	0.035	0.881	0.008	0.030	0.786
Average education of hhd heads	-0.095	0.082	0.248	0.157	0.308	0.610	0.111	0.203	0.587
Payment to hired labor	0.000	0.000	0.886	-0.002	0.002	0.427	0.000	0.001	0.784
Productive assets	3.237	1.596	0.044	1.257	2.444	0.608	3.014	2.317	0.195
Log of value of vehicles owned	0.030	0.073	0.685	0.002	0.138	0.986	0.122	0.150	0.418
Log of distance to Ouro Preto	-0.298	0.353	0.398	1.083	0.615	0.080	0.752	0.536	0.163
Average slope on lot	0.004	0.074	0.958	-0.159	0.141	0.259	0.100	0.121	0.408
Soil suitability	0.935	0.396	0.019	0.342	0.698	0.625	-0.381	0.635	0.550
Productive assets (group)	1.127	4.419	0.799	-7.270	20.011	0.717	31.709	17.001	0.064
Log of value of vehicles owned (group)	-0.254	0.294	0.389	-0.981	0.664	0.142	-0.818	0.704	0.247
N		270			172			171	
Adjusted R-sq		0.448			0.369			0.308	
F-val		19.27			9.37			23.150	
Pr > F		<0.001			<0.001			<0.001	

Clustered standard errors by association membership are reported.
Instruments used in the first stage regression are: group level variables for family size, use of fertilizer and average slope.
Productive assets (group) and log of vehicle value (group) indicate contextual interaction effects.

Improved rural markets, pasture intensification and deforestation – small farmers, milk markets and land use in the Amazon frontier

3.1 Introduction

In 2000, the cumulative deforested area in the Brazilian Amazon was estimated to have exceeded 58.7 million hectares (INPE, 2004)11. According to IBGE estimates, 90% of the deforested area in the Legal Amazon had been converted to pasture by 1996, and 14% of that pasture area was unused and degraded (Barretto, et al., 2005, Fearnside and Barbosa, 1998). Pasture degradation due to mismanagement or poor soil quality is widely blamed for perpetuating a cycle of deforestation, by encouraging farmers to expand pasture either on their current farms or by migrating further into the frontier (Almeida and Campari, 1996, Müller, et al., 2004). These divergent empirical findings on land use and migration outcomes among colonist farmers engaged in small-scale ranching in the Amazon motivates this study of pasture management decisions, their determinants, and their implications.

Considerable policy interest surrounds the issue of whether improved markets create incentives for small farmers to intensify (increase pasture productivity) and/or extensify (deforest to create more pasture) (Lee, et al., 2001). This study focuses on land use decisions made by small farmers (smallholders in the Amazon context own 100 hectares of land in general), a group that constitutes 83% of the rural population and has contributed 47% of accumulated deforestation in the Brazilian Amazon (Pacheco, 2005).

[11] Instituto Nacional de Pesquisas Espaciais estimate – downloaded from http://www.inpe.br

Small farmers face financial constraints on investing in intensive pasture systems that generate non-declining yields (Faminow, 1998, Vosti, et al., 2001). Thicker milk markets (i.e., more buyers competing for farmers' milk) could relax this constraint by increasing the farmgate price of milk. In this paper, I examine if and how improved milk markets encourage farmers to invest in more intensive pasture management.

The implications of more intensive pasture management are also subject to debate. On the one hand, higher profits per hectare from intensive pasture management are desirable in that they would compensate for the ecosystem services lost for every hectare deforested and would probably also increase local income, especially in regions where land is becoming increasingly scarce relative to labor. This could contribute to efficient land management, a more productive landscape and a stable rural population. On the other hand, from an environmental perspective, there is concern that higher profits from more intensive pasture management will attract more investment into the cattle sector and increase the deforestation rate, especially in the context of increasingly integrated markets for inputs and outputs (Angelsen and Kaimowitz, 1998, Southgate, 1994). Further, sustained profitability of pasture could inhibit any transition to forest regeneration and recovery of ecosystem services in old frontiers. Conceptually, these two concerns are contradictory: the productive landscapes that would in some sense compensate for deforestation would also encourage more deforestation and further expansion of the frontier. Empirically, there is little evidence on how intensification

affects the frontier landscape. Impacts on local deforestation and out-migration are likely to vary across regions and years.

Cattle pasture is increasingly dominating the land use portfolio of small farmers in the Amazon in response to higher profits from milk and beef as compared to annual and perennial crops (Barreto, et al., 2005, Shone and Caviglia-Harris, 2006). An important reason for the increasing profitability of cattle ranching has been increasing integration of frontier farmers with regional and national markets (Faminow, 1997, Mertens, et al., 2002). In most of the empirical literature on deforestation and frontier land use, market access is equated to distance to some market center following the von Thünen approach (Angelsen and Kaimowitz, 1998). However, this simple representation of market access ignores complex spatial and temporal issues in market development, and the dynamics between market growth and individual pasture management. Further, there are clearly many other factors driving land clearing and pasture establishment patterns of colonist farmers: land speculation (Muchagata and Brown, 2003, Schneider, 1995), government subsidies (Bulte, et al., 2007, Schneider, 1995), insecure property rights (Alston, et al., 1996, Schneider, 1995), migration history (Almeida and Campari, 1996), biophysical characteristics (Chomitz and Thomas, 2003) and human capital (Angelsen and Kaimowitz, 1998, Walker, et al., 2002). A key question for policy-makers seeking to guide frontier development in the Amazon is to ascertain whether supporting the

development of rural milk markets could encourage farmers to invest in more intensive pasture management, and ultimately stabilize forest cover and frontier populations.

In this paper, I use a panel dataset on land use behavior of farmers in the Ouro Preto do Oeste settlement in Rondônia, Brazil over a decade starting in 1996. In addition, I have compiled information on the evolution of the dairy markets in the region over the same period[12]. This provides the opportunity to empirically examine how farmers adapted their land use strategies to the economic opportunities created from market expansion (increase in the number of milk plants that could potentially buy milk from farmers). This paper thus contributes to the growing literature on the compatibility of agricultural intensification with sustainable natural resource management (Angelsen and Kaimowitz, 2001, Lee, et al., 2001). The following sections of the paper are organized as – sections 3.2 and 3.3 are reviews of the literature on cattle ranching in the Amazon and the role of agricultural market on land use in the Amazon respectively; sections 3.4 reviews the theoretical and empirical literature on agricultural intensification and the environment; section 3.5 outlines a theoretical model of intensification and extensification choice; sections 3.6 and 3.7 describe the study area and the data; section 3.8 provides the empirical results followed by implications of the findings in 3.9.

[12] The market for beef (number of slaughterhouses) remained the same over the period of study (1996 to 2005), whereas, the number of milk processing plants increased from 11 in 1996 to 19 in 2005. Most of the analyses

3.2 Environmental and economic perspectives on cattle ranching in the Amazon

The Brazilian Amazon still accounts for approximately 40% of the world's remaining tropical rainforest and plays a vital role in maintaining biodiversity, regional hydrology, climate, and terrestrial carbon storage (Asner, et al., 2004, Laurance, et al., 2001). Persistent loss of forest cover to extensive pasture-based land use systems cause substantial loss of species, especially plant species (Fujisaka, et al., 1998). Hydrologically, deforestation results in substantial downstream damage from sedimentation and changes in the timing and volume of stream flows (Neill, et al., 2006, Tinker, et al., 1996). Deforestation patterns in Rondônia were found to have micro-climatic changes in levels of precipitation and temperature (Baidya Roy and Avissar, 2002). Poorly managed pastures have been found to be associated with a loss of soil carbon (Cerri, et al., 2007, Desjardins, et al., 2004, Fearnside and Barbosa, 1998). Torras (2000) finds that after accounting for the loss of such non-marketed environmental amenities and ecosystem services, the calculated NPV of the annual loss from deforestation in the Amazonian states was substantial even when compared to overall Brazilian GDP.

Besides such global environmental concern, there persists a debate over the compatibility of pasture with the soil quality in the Amazon frontier. In general, forest soils in the Amazon have properties that limit productivity of cultivated pastures and are

generally low in natural fertility (Serrão, et al., 1979). Burning to clear forests and create pasture releases large amounts of nutrients into the soil and increases pasture production in the first 4-5 years. Some believe that this improvement is only transitory as a decline in the natural productivity of pasture grass is observed consistently within 5-6 years (Hecht, 1993, McGrath, et al., 2001, Serrão and Toledo, 1990). The problem gets exacerbated with high grazing pressure, weed invasion and soil compaction (Nepstad, et al., 1991) that break the equilibrium of a balance of the soil-plant-animal-climate complex (Serrão, et al., 1979). Data from the Agricultural Census in Brazil (1995) reveal that the most productive pastures, with an average stocking density of 1.38 animals per hectare, corresponded to only 20% of the total pasture area in the Amazon, while almost seven million hectares were abandoned and that pastures with stocking below 0.4 animals/ha corresponded to more than 40% of the total area in pasture (Arima, et al., 2006, IBGE, 2005). On a more optimistic note, a study conducted by Embrapa[13] (Falesi, 1976) concluded that conversion of forest to pasture improved soil properties. Alfaia, et al. (2004), Cerri, et al. (2007) and Müller, et al. (2004) note that increases in soil fertility could persist for longer periods with better management practices. Some believe that pastures may be sustained longer than agricultural crops on Amazonian soils because of lower soil nutrient depletion and higher soil organic matter in pastures (McGrath, et al., 2001, Murty, et al., 2002).

[13] Empresa Brasiliera de Pesquisa Agropecuaria – the government agency for livestock research in Brazil

However, the growth of the cattle population in the Amazonian states has been higher than the rest of Brazil, and the state of Rondônia recorded the largest growth among all the states in the Legal Amazon between 1990 and 2006 (IBGE, 2005). Figures in Tables 1 & 2 show that change in cattle herd and increase in area in pasture as a percentage of total area in the state was highest in Rondônia. Given the environmental limitations mentioned earlier, such growth in cattle ranching raises concerns regarding its sustainability as an economic venture for small farmers. Fearnside (2002) argues that financial constraints of small farmers limit investments in replenishing the soil nutrients that are depleted by pastures and is unlikely to permit maintenance of vast areas of pastures. Variations in stocking density of cattle found in studies across the Amazon (Hohnwald, et al., 2006) indicate mixed outcomes in such cattle ranching system (Arima, et al., 2006). Other studies suggest that cattle ranching productivity in some regions can be relatively high and results in attractive rates of return, either immediately after deforestation or in renovated pastures (Arima and Uhl, 1997, Margulis, 2003). Mattos and Uhl (1994) observe that farmers invest in soil quality through tilling and fertilization, and the reported returns per hectare net of costs from such intensification measures were thrice as much as from extensive approaches. Faminow (1998) argues that with improved cattle technologies and extension services, pastures can remain financially viable from the farmer's perspective. Cattle could also be incorporated into mixed farming and increase the profitability of diversified systems (Fujisaka and White, 1998). Stall et al. (2001) find similar evidence that livestock can increase the profitability of mixed farming

systems when manure is used to fertilize crops. Besides income-generating motives, there are other reasons that explain pasture creation and cattle-holding of small farmers – clearing of forests increases property value and cattle ownership is less risky than farming (Pedlowski and Dale, 1992); cattle provide cash liquidity in times of emergency and creation of pasture help claim ownership of land (Costa and Rehman, 2005).

Thus, the sustainability of pasture-based land use system in the Amazon appears to critically depend on how actively farmers manage and maintain long term productivity of the pasture (Muchagata and Brown, 2003).

3.3 Growth of markets for cattle products in the Amazon

Besides supply side issues – like property claims, land speculation, fiscal incentives and other subsidies – Faminow (1997) suggests that the expansionof cattle ranching in the Amazon is fundamentally market driven. It is cheaper to produce milk and beef within the Amazonian states rather than importing these products from Southern states of Brazil to meet the growing demands of the urban population in the Amazon (Arima, et al., 2006). In addition, significant efforts were expended to control Foot and Mouth disease so that the Amazonian states could export cattle products to other regions (Barretto, et al., 2005). 45 of the 68 slaughterhouses and 94 of the 111 milk plants in the Amazon were established between 1994 and 2004 (Pacheco, 2005). The increase in

operation of milk plants was primarily in the states of Mato Grosso, Pará and Rondônia, following the expansion of their main urban centers (Pacheco, 2005). Large companies headquartered in southern Brazil set up processing facilities close to urban centers in high cattle density regions (Almeida, et al., 1995). This rapid expansion in the number of milk production plants, primarily in Rondônia and southern Pará, allowed industrial milk producers to reach distant markets within the country. Schneider, et al. (2000) noted that small dairy ranches, located close to highways, obtain satisfactory returns on investment when they are located close to highways.

From a policy perspective, market access and commercialization of agriculture are regarded as essential conditions for rural income growth and poverty reduction (Fafchamps and Hill, 2005, Shilpi and Umali-Deininger, 2007, World Bank Report, 2007). As Faminow (1998) points out, an increasing frontier population and favorable terms of trade with the rest of Brazil stimulated the demand for beef and milk from the Amazon. This is supported by (Andersen, et al., 2002) as they find high levels of urban GDP and population growth in the Amazonian municipalities with the fastest growth in the cattle herd. Historically, markets for agricultural products in the Amazonian have been monopolistic and transport facilities have been inadequate (Almeida, 1992). This resulted in agricultural prices being depressed and farming being relatively risky. The improvements of the road network and the transport capacity, as well as the introduction of electricity to rural areas have generated new industrial opportunities. As a result, large

processing units have been installed, making remote forest areas more likely to be converted to pasture (Mertens, et al., 2002). Campari (2005) argues that expansion of cattle markets have an important role in reducing the power of typical frontier monopsonies and improve farmer's bargaining power as suppliers of milk and beef. Theoretical work by (Sexton, 1990) also shows how farmer cooperatives could reduce market power for oligopsonies and create a price structure better for the producer. In a municipal level analysis for Brazil, de Castro (2002) finds that agricultural output increased with road density, a variable often used as a proxy for market access[14]. Chomitz and Thomas (2003) note that small farmers tend to be more subsistence-oriented, and better opportunities for them to generate cash income from farm produce is critical for improving household welfare. Besides the potentially beneficial welfare impacts of improved markets, higher returns allow small farmers to cover opportunity costs which makes it worthwhile for them to continue farming in the frontier rather than migrating to new areas (Campari, 2005). However, the same author notes that farmers who capitalize on such marketing opportunities also tend to deforest more on their parcels.

This leads to the investigation of whether improved markets can lead farmers towards pasture intensification, and implications of such intensification for deforestation on the farm and out-migration to the forest frontier.

[14] For a review of impact of road networks on deforestation and development, see Appendix A, B in Chomitz, K. M. "At loggerheads? : agricultural expansion, poverty reduction, and environment in the tropical forests." World Bank policy research report.

3.4 Review of literature on agricultural intensification and the environment

Development of the agricultural sector has long been considered critical for achieving food security objectives in developing countries. However, placed in the broader context of rural development, agricultural growth at the expense of local natural resources has been deemed unsustainable (Vosti and Reardon, 1997). This spawned interest in identifying technological and market conditions that could lead to agricultural intensification to achieve economic development and environmental conservation in tandem (Lee, et al., 2001). Economic theory generally does not support the common assumption that intensive production systems will prevent extensive land use practices that are environmentally destructive (Pagiola and Holden, 2001). For example, DeShazo and DeShazo (1995) suggest that in the forest frontier, progress in agriculture technology increases production and farm profits and increases forest clearing. Angelsen and Kaimowitz (2001) note that pure yield-increasing or labor-intensive technological change in the intensive agriculture sector could reduce deforestation pressure as the same income could be generated from a smaller agricultural plot. These authors identify cattle-based farming systems to produce beef in Latin America as labor-saving and thus likely to promote deforestation. Increased integration of commodity and labor markets have also been found to unambiguously increase rates of forest clearance (Pendleton and Howe,

2002)[15]. In contrast, Reardon, et al. (2001) conclude that improved access to agricultural input and product markets reduces the risk of investing in sustainable production technologies, creates more profitable alternatives to traditional extensive agriculture, and therefore potentially reduces pressure on the environment.

Much of the empirical literature on pasture management in the Amazon suggests that improved production technology encourages deforestation. Reis and Margulis (1994) found that deforestation rates were positively correlated with cattle density in a municipal level analysis in the Amazon. Using a CGE model, Cattaneo (2001) finds that improvements in livestock technology provide highest returns to farmers but dramatically increase long run deforestation. Limits on financial resources and on physical inputs such as phosphates are indicated as factors that diminish the prospects of maintaining non-decreasing levels of productivity in the majority of pastures in the region (Fearnside, 2002). In a cross-sectional analysis, Seidl, et al. (2001) find negligible increase in pasture area consequent to an increase in the size of the cattle herd but a much larger impact of mechanization on forest clearing among farmers with a tractor, which supports the theoretical prediction that labor-saving technological change promotes deforestation. Even in the situation of labor scarcity that characterizes many parts of the Amazon, returns to labor in low-intensity livestock system exceed that in perennial agriculture or

[15] See (Pendleton and Howe, 2002) for a review of how market access affects land clearing by small farmers

forest extraction and lead small farmers towards more forest clearing for pastures (Vosti, et al., 2002). Integration of the frontier into regional markets leads to higher rates of deforestation (Vosti, et al., 2001). Walker, et al. (2000) find that following such market integration in parts of Western Amazon, changes in the producer prices favored beef and milk over other cash crops and encouraged extensification of pastures.

On the other hand, there is another school of thought that proposes that that new low-cost forages and management techniques will reduce pressure upon forest cover by renewing productivity in degraded and abandoned land. Technological intensification and consequent improvement in the sustainability of forest-replacing pastures can significantly increase the productivity of cattle raising operations in the Amazon can be significantly increased (Serrão and Homma, 1993). However, adoption rates of intensive pasture management will only increase if capital constraints for farmers could be eased to allow them to invest in better management practices (Faminow, et al., 1999, Vosti, et al., 2001). Though earlier surveys found no evidence that farmers were engaged in pasture fertilization (Serrão, et al., 1979), studies in the 1990s from the eastern Amazon do indicate that some small farmers were rejuvenating old, degraded pastures back into production by tilling, reseeding with better adapted forages, and fertilizing (Arima and Uhl, 1997, Mattos and Uhl, 1994).

The investment required to restore pastures is considerable, but returns are generally 3-10 times greater than from more extensive ranching approaches (Mattos and Uhl, 1994). Muchagata and Brown (2003) observe that suitable market conditions facilitate adoption of intensification measures to create durable pastures, and this effect is stronger among small farmers with lower endowments of capital. The development of market networks in the livestock sectors have integrated remote areas of the Amazon and contributed to sustainable regional development and land management (Mertens, et al., 2002). Improved access to markets boosts commodity prices and encourages farmers to revitalize production on already cleared parcels (White, et al., 2001). Improvement in the transportation infrastructure is a requisite for market expansion. While investments in public services that foster rural development are often conditional on road infrastructure (Nepstad, 2001), the bulk of evidence (Pfaff, 2007) is that roads also facilitates deforestation.

Intensification of cattle ranching in the Amazon will require both – (a) management of the productivity of the pasture, and (b) management of the cattle herd (Muchagata and Brown, 2003). Pasture reform for (a) consists of removing invading vegetation, tilling the land, planting better-adapted grasses and applying fertilizer (Schneider, et al., 2000). Fearnside (2002) identifies options for (b) including genetic improvement of cattle herds, better regulation of stocking densities and construction of fences for rotation of grazing areas. The productivity of the cattle herd could also be increased by providing more veterinary and supplemental feeds (Carpentier, et al., 2000).

The outcome of these measures should be reflected in higher productivity per hectare of pasture and per unit of cattle (Vosti, et al., 2001).

3.5 Conceptual framework

In this section, I develop a two-period household production model to examine how a representative farmer allocates land, labor and financial resources to extensification and/or intensification decisions as market opportunities change. Consider a household maximizing utility indicated by the concave, continuous and twice differentiable function $U_t(C_t, l_t; \psi)$, where C_t and l_t denote consumption of a composite market good and leisure respectively in period $t = 1,2$. (ψ) represents the set of preferences and family-specific unobserved characteristics. The farmer has an initial endowment of labor $(\overline{L})$ and land $(\overline{A})$, with (A_1) in pasture and (F) in forest. Farmers raise cattle to produce milk and sell it to the local milk plants for cash income. The production function of milk is convex and continuous with labor $(L^m{}_t)$, land (A_t), herd size (H_t) and soil quality (S_t) as arguments – $M(L_t^m, A_t, H_t, S_t; \xi)$. This production function is characterized as $M_k > 0, M_{kk} < 0$ where $k = L^m, A, H, S$. (ξ) represents biophysical characteristics of the property other than soil quality, like elevation and hydrology that affect milk production but are exogenous to the farmer. Based on the results on imperfection of labor markets (Table 5), the household production model is

considered to be non-separable as developed in (Singh, et al., 1986, Takaski, 2007). Thus farmer's consumption and milk production decisions are interdependent or recursive.

In period 1, the farmer has the choice of allocating labor to clear forest and create more pasture $\left(\beta.L^e\right)$, where L^e denotes labor units devoted for extensification and β is the efficiency with forest is cleared per unit of L^e (Pagiola and Holden, 2001, Takasaki, 2007). Assume that $\beta > 0$. The amount of pasture created in period 1 is put into milk production in period 2.

The farmer also has the choice of allocating labor and financial resources to intensification in period 1. In the model, intensification can proceed in two ways – (1) labor allocated to replenish soil productivity $\left(L^I\right)$; (2) purchase cattle of better genetic quality that produces more milk per unit such that $H_2 = \alpha(I).H_1$, where $\alpha(I)$ indicates and increase in milk productivity of the herd, with $\alpha(I) > 1$ if $I > 0$, $\alpha(I) = 1$ if $I = 0$.

The decline in soil fertility appears in the model in two ways – (1) a linear soil fertility function (Romano, 2001) is specified which takes into account labor allocated to soil conservation measures that improves soil productivity, such that $S_2 = S + \theta.L^I$, where $\left(S\right)$ represents the intrinsic quality of the soil and $\left(\theta.L^I\right)$ reflects outcomes of soil

conservation measures undertaken by the farmer with $(\theta > 0)$. By construction, $S_1 = S$. (2) The amount of pasture in period 1 (A_1) faces a productivity decline in period 2 by a factor $(\eta < 0)$. This captures the reality of declining pasture productivity that gets mentioned in the literature, necessitating active pasture management by the farmer to maintain non-declining milk yield.

There is a land market where only cleared land in valued. In the Amazon, this simplification captures the fact that cleared land is more valuable than land with forest. In each period, the farmer has the option of selling the land that has been cleared on the lot.

The dynamics of the model arises from the fact that decisions made in period 1 have repercussions in period 2. For example, $L^e > 0$ in period 1 is an investment that farmer makes that incurs an opportunity cost in terms of foregone wage income in period 1, but increases cash income in period 2 from higher amount of milk production. Clearing in period 1 also increase the amount of cleared land on the lot and raises the property value that he can sell in period 2 - $P_a(A_1 + \beta.L^e)$. Similarly, if $I > 0$ and/or $L^I > 0$, then the farmer foregoes consumption opportunity and wage income in period 1 by allocating financial and labor resources to intensification decisions, but increase cash income from milk production in period 2.

The farmer faces a budget constraint in period 1 where the amount of expenditure on the consumption goods C_1 (with a numeraire price) and intensification I cannot exceed the income from sale of milk and cleared land in period 1. Similar conditions hold for period 2, except there are no expenditures on intensification.

The two-period model can be written as a utility maximization decision for the farmer as:

Maximize: $U_1(C_1, l_1) + \delta . U_2(C_2, l_2)$

Subject to:

$P_1^m . M\left(L_1^m, A_1, H_1, S\right) + P_a . \left(A_1 - a\right) \geq C_1 + P_I . I$ budget constraint 1

$\overline{L} \geq L_1^m + L^e + L^I + l_1$ labor constraint 1

$\overline{A} \geq A_1 + \beta . L^e + F + a$ land constraint 1

$P_2^m . M\left[L_2^m, \left(\eta . A_1 + \beta . L^e\right), \alpha(I) H_1, \left(S + \theta . L^I\right)\right] + P_a . \left(A_1 + \beta . L^e\right) \geq C_2$ budget constraint 2

$\overline{L} \geq L_2^m + l_1$ labor constraint 2

The Lagrangean for this problem will be:

$$Z = \begin{bmatrix} U_1(C_1, l_1) + \lambda_1 \left[P_1^m . M\left(L_1^m, A_1, H_1, S\right) + P_a \left(A_1 - a\right) - C_1 - P_I . I\right] \\ + \mu_1 \left(\overline{L} - L_1^m - L^e - L^I - l_1\right) + \phi_1 \left(\overline{A} - A_1 - \beta . L^e - F + a\right) \end{bmatrix}$$
$$+ \delta . \begin{bmatrix} U_2(C_2, l_2) + \lambda_2 \left(P_2^m . M\left[L_2^m, \left(\eta . A_1 + \beta . L^e\right), \alpha(I) H_1, \left(S + \theta . L^I\right)\right] + P_a . \left(A_1 + \beta . L^e\right) - C_2\right) \\ + \mu_2 \left(\overline{L} - L_2^m - l_2\right) \end{bmatrix}$$

The first-order conditions are:

$$\partial Z / \partial C_1 = U_{C1} - \lambda_1 = 0 \quad (1)$$

$$\partial Z / \partial C_2 = \delta(U_{C2} - \lambda_2) = 0 \quad (2)$$

$$\partial Z / \partial L_t^m = \lambda_t . P_m^t M_L - \mu_t = 0 \quad \text{for t = 1, 2} \quad (3)$$

$$\partial Z / \partial l_t = U_{lt} - \mu_t = 0 \quad \text{for t = 1, 2} \quad (4)$$

$$\partial Z / \partial L^e = -\mu_1 - \beta.\phi_1 + \delta.\lambda_2.\beta(P_m^2.M_A + P_a) \le 0; \; L^e \ge 0; \; \partial Z / \partial L^e . L^e = 0 \quad (5)$$

$$\partial Z / \partial L^I = -\mu_1 + \delta.\lambda_2.P_m^2.\theta.M_S \le 0; \; L^I \ge 0; \; \partial Z / \partial L^I . L^I = 0 \quad (6)$$

$$\partial Z / \partial I = -\lambda_1.P_I + \delta.\lambda_2.P_m^2.\alpha'(I).M_H \le 0; \quad I \ge 0; \; \partial Z / \partial I . I = 0 \quad (7)$$

$$\partial Z / \partial a = -\lambda_1.P_a + \phi_1 \le 0; \quad a \ge 0; \; \partial Z / \partial a . a = 0 \quad (8)$$

The Shadow wage rate can be defined as:

$$\omega_t = \mu_t / \lambda_t = P_m^t M_L \qquad \text{for t=1, 2} \qquad \text{using (3)}$$

This is similar to the standard result where the shadow wage rate of the farmer equals the value of marginal product of labor in milk production on the farm.

The farmer will allocate no labor resources to extensification if:

$$\delta.\lambda_2.\beta.P_m^2.M_A - \beta.\phi_1 \leq \mu_1$$

or, $$\delta.\beta.U_{C2}.P_m^2.M_A - \beta.P_a.U_{C1} \leq U_{C1}.P_m^1 M_L$$

or, $$\delta.\beta.U_{C2}.P_m^2.M_A \leq U_{C1}(\omega_1 + \beta.P_a) \quad (9)$$

According to this condition, the LHS indicates the present value of the utility in future from the increased value marginal product of milk production due to increase in area in pasture. The RHS term is the reduction in utility in the first period from having diverted labor into extensification from earning wages and foregone consumption from the money spent in acquiring more land. Thus, a farmer will be averse to engage L^e in period 1, if the long term benefit from increased milk production is lower than the current costs of diverting labor and financial resources to creating pastures and/or buying more land. Factors that could lead the farmer to engage in extensification are:

(a) Higher price of milk in future

(b) Lower price of land that could be purchased

(c) Lower opportunity cost from off-farm income

The farmer will allocate labor to intensification if:

$$\delta.\lambda_2.P_m^2.\theta.M_S \leq \mu_1$$

or, $$\delta.U_{C2}.P_m^2.\theta.M_S \leq U_{C1}.P_m^1.M_L$$

or, $$\delta.U_{C2}..P_m^2.\theta.M_S \leq U_{C1}.\omega_1 \quad (10)$$

According to this condition, the LHS indicates the present value of the utility in future from the increased value marginal product of milk production due to improvement in soil quality due to conservation measures adopted by the farmer. The RHS term is the reduction in utility in period 1 from foregone wages as farmers devote L^I to intensification. Factors that could lead a farmer to engage in intensification are:

(a) Higher price of milk in future

(b) Higher θ indicating the efficiency of soil improvement measures

(c) Lower opportunity cost from off-farm income

The farmer will allocate financial resources to improving the productivity of the cattle herd if:

$$\delta.\lambda_2.P_m^2.\alpha'(I).M_H \leq \lambda_1.P_I$$

or, $$\delta.U_{C1}..P_m^2.\alpha'(I).M_H \leq U_{C1}.P_m^1.M_L.P_I$$

or, $$\delta.U_{C1}..P_m^2.\alpha'(I).M_H \leq U_{C1}.\omega_1.P_I \quad (11)$$

According to this condition, the LHS indicates the present value of the utility in future from the increased value marginal product of milk production from the increase in higher-yielding varieties of cows in the herd. The RHS term is the reduction in utility in period 1 due to foregone wages and diversion of money from consumption to purchase of genetically improved varieties of cattle. Factors that could lead a farmer to invest more in intensification are:

(a) Higher price for milk in future

(b) Higher milk yield of the improved variety of cows captured by $\alpha(I)$

(c) Lower price of improved variety of cows

(d) Lower opportunity cost from off-farm income

In the context of the study, the impact of expansion of local milk markets on intensification and extensification is thus ambiguous. If competition among more milk plants increases the selling price of milk, then the model above shows that farmers will have an incentive to engage in both. The final decision will be determined by the relative strengths of land clearing efficiency β, the improvement in soil productivity θ, the price and productivity of genetically improved cattle $P_I, \alpha(I)$.

3.6 Description of the study area

The study area is the colonist settlement in *Ouro Preto do Oeste*[16] in the state of Rondônia in Western Brazil (Figure 3.1). Designed as a model colonization project by INCRA (National Institute for Colonization and Agrarian Reform) in 1970, the region (comprising six municipalities) has witnessed an increase in population from 8893 in 1970 to 82,918 in 2007 (Hogan, 2000, IBGE, 2007)[17]. Waves of immigration from

[16] The settlement of Ouro Preto do Oeste comprises of six municipalities – Ouro Preto, Vale do Paraíso, Nova União, Mirante da Serra, Teixeirópolis and Urupá.
[17] Compiled from UNICAMP report (2000) and Contagem da População 2007, IBGE (Instituto Brasileiro de Geografia e Estatistica)

Southern Brazil, coupled with the paving of the arterial highway (BR-364) and establishment of secondary roads led to widespread deforestation (Browder, et al., 2004). As evident in Figure 3.2, deforested land now dominates the landscape with only isolated remnants of the original tropical forest. A review of findings from previous field surveys in the *Ouro Preto do Oeste* region reveal that while an average lot of a small farmer in 1980 had more than 50% of forest (Leite and Furley, 1985), the corresponding figure a decade later in 1991 were less than 40% (Pedlowski and Dale, 1992) and 18% in 2000 (Caviglia-Harris, 2004). From the interpretation of classified Landsat imagery representing the study area, I find that 64% of the primary forest that existed in 1990 was cleared by 2005. Similar extent of deforestation (more than 70% of total land area) are observed in land cover change analysis conducted at a larger spatial scale in central Rondônia (Alves, et al., 1999).

These colonists have traditionally derived a major portion of their livelihood from cultivating crops and/or raising cattle on land obtained from cleared forests (Jones, et al., 1995). Land use choices of these farmers thus leave a critical imprint on the landscape in the frontier, as 96% (83%) of the farmers owning less than 500 (100) hectares of land were responsible for 43% (18%) of the deforestation in the Legal Amazon (Pacheco, 2005) in 1996. Between 1996 and 2006, the percent of total area in pasture increased from 33% to 58% in Rondônia (Table 3.1). At the same time between 1990 and 2005, the highest growth rates in cattle population in the Amazon was found in the state of

Rondônia – from 1.7 million heads in 1990 to 11.3 million in 2005 (IBGE, 2005) (Table 3.2). In 2005, almost 9% of the total cattle population of Rondônia was being raised within the six municipalities in the study region. If only milk cattle are considered, 23% of the total herd was concentrated within the study area, indicating the importance of milk production in the region (Tables 3.3 and 3.4 in Appendix)[18]. As evidence of this trend, the per capita ownership of cattle in the region increased from 2.9 in 1991 to 13.7 in 2005 (IBGE)[19]. Farmers with a larger cattle herd were also responsible higher levels of deforestation on their lots (Caviglia-Harris, 2005).

Among all INCRA settlements in the Brazilian Amazon, those in Rondônia have the highest percentage of titled land (Almeida, 1992, Leite and Furley, 1985). Among a sample of farmers surveyed by (Jones, et al., 1995) in the Ouro Preto settlement, there was evidence in favor of lengthy survival of families on the same lot and little evidence of land speculation indicating lower rates of turnover compared to other parts on the frontier. The superior soils in Rondônia, relative to those in the Trans-Amazon region, may contribute to the longer tenure and high productivity for prolonged durations (Jones, et al., 1995, Pedlowski and Dale, 1992). Rondônia experienced the dramatic increase in

[18] If adjacent municipalities of Jaru and Ji-Parana are also considered, then the region as a whole accounts for almost 40% of the total milk cattle in Rondônia in 2005. This indicates why the region is referred as 'bacia leiteira' (milk basin) of the state.
19 Source: Pesquisa Pecuária Municipal (http://www.sidra.ibge.gov.br/bda/acervo/acervo2.asp?e=v&p=PP&z=t&o=21)

the number of cattle in spite of the fact that the least amount of subsidies for cattle development flowed into the region (Andersen, et al., 2002). The region falls in the transitional rainfall zone receiving 1700-2200 mm/year that facilitates re-growth of pasture grass (Schneider, et al., 2000). Thus, the factors like tenure security, soil quality and government subsidies that are commonly cited in the empirical literature on deforestation in the Amazon do not vary in the Ouro Preto settlement. This creates a favorable situation to examine the impact of market integration on management of pastures, as the confounding effects of the other relevant variables are minimized.

In a survey conducted in early 1980s, (Leite and Furley, 1985) observed no milk processing facilities serving the population in the study area, the pastures had low cattle stocking density and farmers were producing milk only for domestic consumption or for home-made cheese . In a subsequent study, (Martine, 1990) identified that distance to markets was a limiting factor for agricultural growth in the region. (Pedlowski and Dale, 1992) report that 75% of farmers produced milk in 1991, but less than 50% of them sold it to processing plants in Ouro Preto and Ji-Parana. More recent studies find that integration of market networks for cattle products in the region has provided farmers significant financial incentives to allocate land and other capital to cattle husbandry (Caviglia-Harris, 2004). Figure 3.3 in the Appendix illustrates the expansion of the milk processing plants in the study region over time. While there were 11 milk plants in the region prior to 1996, 8 more were established within the study area since then indicating

the economic importance of milk production in the region. The usual practice if for the milk plants to send collection trucks that gather the milk from the farmer' parcels in the morning. (Pedlowski and Dale, 1992) notes that farmers had to pay a premium for transportation to the milk plants in 1991. Thus, farmers living further from the paved roads and the municipal towns faced a price disadvantage (Caviglia-Harris, 2005). However, during the field surveys in 2005 and 2006, no farmers in the sample were directly charged for transportation, and some claimed that waving the transportation cost was an incentive that milk plants use to woo farmers to become suppliers of milk. There are only 2 registered slaughterhouses based in the towns of Jaru and Ji-Parana and have been in operation from early 1990. Thus, the market for beef in the region has not gone through the dramatic expansion like the local milk industry. Though small farmers own cattle for dual production, income from milk is found to be more important than beef among them (Jones, et al., 1995).

3.7 Description of data

The dataset comprises of 3 rounds of household surveys conducted in 1996, 2000 and 2005. The sample size in each survey year differs as the sample was increased in successive years and some farmers who had moved out of their initial parcel could not be interviewed. There were 146 farmers interviewed who have been living on the same lot in all the survey years and those are included in the 'balanced panel'. Besides, interviews

were conducted with a smaller subset of farmers in 2006, with specific questions asked on the investments they made to enhance pasture productivity and herd maintenance since 1996. This sample consists of 96 farmers and is referred to as the 'restricted panel'. In 2006, interviews were also conducted with personnel at all the milk processing plants collecting milk from the farmers in the study region to get precise estimates of the catchment area of milk supply for each plant. This data provides an idea of the choice set that a farmer had as supplier of milk in each of the survey years. Based on the theoretical model, variables reflecting extensification (change in area in pasture and forest), intensification decisions (investments in pasture and cattle productivity), demographic factors (age, family labor, prior experience), socio-economic status (asset ownership, hired labor) and biophysical factors are described.

Milk plants: As indicated in Figure 3.3, the expansion in the number of milk plants mostly took place within the study area close to each of the municipal towns. In Table 3.5, the profile of all the plants collecting milk from farmers in the study area is presented. All the municipalities in the study area have 2 or more plants in operation. Information was collected from milk plant managers that included retrospective questions regarding area of collection, capacity of plants, number of suppliers and average price offered to farmers. Note that plants with higher capacity travel significant distances to collect milk, while the smaller plants have a much smaller catchment area of suppliers. Since 2001, the larger plants are increasingly changing their manufacturing strategy

(more pasteurized milk rather than cheese, butter and cream) and are buying only cold milk or superior quality of milk. This is one of the reasons why they travel greater distances in search of farmers who meet the quality standards of the plant. Smaller milk producers tend to sell milk to smaller, localized plants as they mostly produce butter and cheese from low quality milk. Another factor that makes a farmer attractive as a supplier is the quantity of milk daily produced. As plants want to avoid operating with excess capacity, they often provide pecuniary and other benefits to lure the farmer to sell milk to them. Another indication of how large the catchment area for each plant is gets reflected in the number of trucks that they use to collect milk. In most cases, the plants send the milk trucks out early in the morning to collect milk from the doorstep of each farmer. Thus a farmer could potentially sell milk to all the plants that send their respective milk trucks along the secondary road that passes in front of the lot of the farmer. The average distance for a farmer to the nearest milk plant fell from 18.76 km in 1996 to 15.77 km in 2005. The average number of plants that a farmer had the option to sell milk to increased from 1.96 to 5.12 in the same period. Thus, in 2005, there were about 5 plants competing with each other to buy milk from a farmer. In Table 3.6, a list of the factors that farmers reported to have influenced their choice of milk plants is given. Note that the time when farmers report to have started selling milk, they had no other option besides selling to the only milk plant that collected milk from them. With time and more competition among the milk plants, the farmer chose the plant that was offering the better price as well as based on personal relations they had with a particular truck driver who often brought

them provisions from the market thus saving the farmer a trip. Based on field interviews, there is unanimity among farmers and personnel at the milk plants that expansion of the local milk industry drove up milk prices over time.

Investment in livestock and pasture: Farmers in the region were not found to actively manage the pastures in previous surveys conducted in the region (Jones, et al., 1995, Pedlowski and Dale, 1992). Unlike other regions in the Eastern Amazon or Mato Grosso, farmers in Rondônia received the least amount of subsidies and government credit to invest in cattle ranching (Andersen, et al., 2002). From the information collected through the household survey in 2006, the different kinds of pasture intensification activities that farmers invested in are reported in Table 3.7. Compared to 1996 when few farmers engaged in intensification, many more reported having invested either in improving productivity of the herd and/or the pasture in 2005. The survey results reported in Table 3.8 clearly indicate the rise in the use government credit in livestock and pasture management between 1996 and 2005. However, as noted by (Bulte, et al., 2007), government subsidies in Brazil have not yet translated into investment in intensification of farming systems. In our sample, more than 90% of the farmers invested at least a part of the credit they obtained from government banks into pasture intensification activities. While per household investment in milk production (buying cows of better genetic variety, providing feed supplements and vitamins to the herd) grew from 713 R$ in 1996 to 2975 R$ in 2005, per household investments in pasture management (planting better

grass, mechanized tilling, use of herbicides and fertilizers, constructing fences for rotational pasture) was non-existent in 1996 but rose to 1141 R$ in 2005. Farmers are increasingly constructing corrals and using mechanized milking to ensure that the milk is collected under more hygienic conditions. These factors are not directly related to pasture management, but help to command a higher price and boost revenue.

In Table 3.8, descriptive statistics of the other variables used in the empirical analyses are presented for the panel dataset.

Land use: Based on survey data, average area devoted to forest and crops (annual and perennial) consistently declined over the years, while the area in pasture increased by more than 12 hectares between 1996 and 2005. Thus, there is evidence of extensive pasture use by small farmers in the region.

Demography: Families have become smaller over the years indicating divisions within the family of migration of family members to other areas. Income from off-farm sources have also significantly increased over the years, often surpassing income from farm produce. The labor market in the urban centers of Ouro Preto do Oeste, Jaru and Ji-Parana are becoming more organized, where much of the off-farm labor opportunities are available. At the same time, the percentage of farmers hiring labor to work on their farms increased in our sample from 23% in 1996 to 67% in 2005. The tests to check for

completeness of labor markets are provided in Table 3.9, 3.10 in the Appendix. Following (Benjamin, 1992, Pattanayak and Butry, 2004), I test if the household compositional variables like family size, average age of household heads, proportion of adults in the family significantly explain hired labor demand. If these variables are statistically unrelated to labor demand, then I could conclude that the labor markets are perfect and farmers could hire in labor to substitute for family labor. Tables 3.9 and 3.10 contain the results from the test for completeness of labor markets, where the family composition variables are regressed on a dummy if the household hired labor. Two sets of results are presented using the full sample in each survey year as well as the 'balanced panel' of farmers. At least one of the household variables is individually significant and the household variables are jointly significant for each model except for the panel in 2000. From these results, I conclude that the labor markets in the region, which has implications for the theoretical model in the next section.

Cattle: The herd grew significantly from 77 per farmer to 99 in 2000 and then fell slightly to 98 in 2005. The stocking density shows a non-linear trend, having reached a peak in 2000 to tail off in 2005[20]. The proportion of milk cattle in the total herd has remained

20 These values are higher than the estimates found in the literature - lower than 1.5 animals per hectare (Desjardins, T., et al. "Effects of forest conversion to pasture on soil carbon content and dynamics in Brazilian Amazonia." *Agriculture, Ecosystems & Environment* 103, no. 2(2004): 365-373.; 2.2 head per hectare in Pedro Peixoto, Acre and 1.6 head per hectare in Theobroma, Rondônia (Fujisaka, S., et al. "Slash-and-burn agriculture, conversion to pasture, and deforestation in two Brazilian Amazon colonies." 59, no. 1-2(1996): 115-130.; between 1.1 and 1.3 heads/ha in the Amazon (Muchagata and Brown 2003); Andersen, L. E., et al. *The dynamics of deforestation and economic growth in the Brazilian Amazon.*

steady at 0.23. While stocking density is used as one of the indicators of intensification as it reflects efficient use of the herd and the pasture (Faminow, 1998), as a caveat, I also mentions that high stocking densities over long period of times could lead to overgrazing and hastens the decline in productivity of pastures (Costa and Rehman, 2005).

Milk price: The average price of milk received by farmers has increased over time, from 0.15 cents per litre in 1996 to 0.26 cents in 2005. Farmers and personnel at the milk plants verified that farmers supplying a greater daily amount of milk received a higher price. With the awareness among the farmers after the campaigns to eradicate the Foot and Mouth disease, many farmers have built corrals and bought mechanized milking machines to make milk collection more hygienic. Milk plants reward farmers who follow these procedures by paying a higher price in exchange of better quality of milk. Communications with farmers revealed the stiff competition among plants to capture farmers producing large quantities of milk daily, as plants try to avoid operating with excess capacity in their plant. In order to attract farmers who either produce better quality or greater quantity of milk, plants engage in paying a premium (called 'bonus') above the base price per litre of milk.

Cambridge: Cambridge University Press, 2002. has a table on changing stocking intensity in the Amazonian states from 1970-1995.

Using the survey data, the variables used to measure outcomes of *extensification* are – (1) the percent of land in pasture on the parcel; (2) change in area in pasture between two survey years; (3) deforestation between two survey years. The indicators of outcome of *intensification* are – (1) investment in pasture improvement; (2) investment in cattle productivity; (3) milk produced per unit of pastures; (4) milk produced per head of milk cattle; (5) stocking density of cattle; (6) principal component obtained from combination of measures related to intensification[21]. The first two intensification variables should reflect economic returns from concerted management efforts to improve productivity of pastures and cattle herd respectively. Stocking density is commonly used to reflect the carrying capacity of the pasture.

3.8 Empirical methods and results on extensification and intensification decisions

The challenge is to estimate the impact of market expansion on pasture management choices of farmers. Market expansion is defined as the increase in density of buyers of milk (the milk plants), using information on the number of plants that a farmer could sell to, and the average distance of nearest 4 plants from the farmer's lot. As more

[21] The Principal Component Analysis (PCA) was carried out to combine the following variables – investment in pasture improvement, investment in cattle productivity, count of activities engaged in for pasture improvement, count of activities engaged to improve productivity of cattle, quantity of milk per unit of pasture, quantity of milk per unit of milk cattle. The PCA was performed on the reduced panel for each cross-section separately - to use the information on investment in pasture and cattle improvement only collected in 2006 for the reduced sample, and to take into account the difference in the means and variances of each variable in the survey years. The proportion of total variation explained by the first components in 2005, 2000 and 1996 were 42%, 40% and 46% respectively.

milk plants began operating in the study region, there was greater competition among the plants to capture sellers (farmers), and an upshot of this competition was that the farmgate price for milk increased. I assume that such market expansion affects farmer's pasture management decisions through the increase in milk prices, thought there could also be direct effects that do not necessarily occur through the price mechanism.

Four different models are estimated – (1) Seemingly Unrelated Regressions to estimate how market expansion affects extensification and intensification decisions directly; (2) 3SLS estimation and (3) Fixed effects panel models where market expansion impacts extensification and intensification decisions through the milk price; (4) Seemingly Unrelated Regressions with lagged value of milk price. Two sets of results for each model are presented – one for the 'balanced panel' and the other for the 'reduced panel'. The reason for using the 'reduced panel' is that additional data on credit use, investments in cattle herd and pasture improvements are available only for the reduced sample. For models (2) and (3), I use average distance to 4 nearest milk plants (which decreased from 39.7 km in 1996 to 27.3 km in 2005) and number of plants that a farmer can sell to as instruments for price of milk to account for its endogeneity. Other explanatory variables used in the models are selected based on previous empirical research on household-level determinants of deforestation behavior in the Amazon (Browder, et al., 2004, Walker, et al., 2002).

In the following section, I present the results from these estimations and discuss their implications.

3.8.1. Seemingly Unrelated Regressions for direct impact of market expansion on extensification and intensification decisions:

The rationale behind specifying the SUR model is to account for the fact farmers could simultaneously take decisions on intensification and extensification. From the theoretical model, solution to the relationships (9 – 11) in equilibrium will provide solutions for the extensification and intensification variables. The reduced form equations for these will be functions of a vector of demographic and location-specific variables (X) and indicators of market expansion (z). These equations could then be written as:

Extensification: $E_{it} = \alpha_{et} + \beta_e.z_{it} + \gamma_e.X_{it} + \varepsilon_{it}^e$

Intensification: $I_{it} = \alpha_{It} + \beta_I.z_{it} + \gamma_I.X_{it} + \varepsilon_{it}^I$ (1)

If these two outcomes are simultaneously determined by the farmer, then the same unobserved factors in the error terms will cause $(\varepsilon_i^e, \varepsilon_i^I)$ to be correlated with each other. As a result, OLS estimation will be inconsistent. As all the parameters related to extensification and intensification is of potential interest, the SUR estimation strategy proposed by Wooldridge (2002) is used.

The results from these models are presented in Tables 3.11 and 3.12. In these models, the primary variables of interest are those related to market expansion – number of plants and average distance of 4 nearest milk plants. I want to examine if market expansion has any direct impact on extensification and intensification choices of farmers. While extensification is measures by the percent of the lot that is in pasture, the intensification indicators are quantity of milk per unit of pasture, quantity of milk produced per head of cattle, stocking density for the 'balanced panel', and additional indicators like investment in improving cattle and pasture productivity, and principal components of all these previous indicators for the 'reduced panel'.

Market expansion appears to have a much stronger impact on extensification than intensification outcomes. In both the 'balanced panel' and the 'reduced panel' estimations, the percent of land owned allocated to pasture increased as more plants were established near the farmer's lot (average distance to the nearest 4 milk plants decreased). While the coefficient with number of plants is positive indicating a similar qualitative result, the coefficient is significant at the 15% level in case of the 'balanced panel' and insignificant in the 'reduced panel'. Overall, the market expansion fair poorly in explaining intensification outcomes. The only cases of significance are observed in the 'reduced panel', where farmers increase the stocking density as the number of plants they can sell to increases, and the investment in pasture improvement increases as the average distance of plants decrease. Farmers with larger lots (using the dummy of new

municipality to indicate smaller lot size) increased the proportion of pasture on their lot by 8% (13%) in the balanced (reduced) panel. While farmers with larger lots had consistently lower milk production per unit of pasture and cattle across the two samples, the 'reduced panel' shows that they also invested more in improving pasture and cattle productivity.

Having found weak evidence for direct effect of market expansion on extensification and intensification, in the next steps I examine if there is stronger evidence in favor of milk prices affecting pasture management decisions.

3.8.2. 3SLS models of intensification and extensification decisions (endogenous milk price):

The rationale for the 3SLS model is the same as for the SUR – farmers are still assumed to make decisions regarding extensification and intensification. However, unlike the previous case, I want to examine if market expansion affects these choices through milk prices. Milk price (p) is treated as an endogenous variable, with average distance of 4 nearest milk plants and number of buyers of milk as instruments[22]. Following a similar mode specification as in (1), the 3SLS model can be written as:

[22] If average distance of milk plants and number of plants to sell milk to were significant in model (1), these variables would not have worked as instruments in model (2).

Extensification: $E_{it} = \alpha_e + \beta_e . p_{it} + \gamma_e . X_{it} + \varepsilon_{it}^e$

Intensification: $I_{it} = \alpha_I + \beta_I . p_{it} + \gamma_I . X_{it} + \varepsilon_{it}^I$

Milk price: $p_{it} = \alpha_i + \eta . z_{it} + \varepsilon_{it}^m$ (2)

The assumption of unobserved individual-specific variables causing correlation among the error terms $\left(\varepsilon_i^e, \varepsilon_i^I, \varepsilon_i^m\right)$ is still maintained. Price (p) is endogenous to the model, and is instrumented using (z).

The data from the three surveys are pooled and the results for the balanced panel (Table 3.13) and reduced panel (Table 3.14) are consistent across both. Higher milk price encourages farmers to have a greater percent of area in pasture on their lot, one of the indicators of extensification – an increase in milk price by 1 centavos[23] leads to farmers increase land allocated to pasture by roughly 2%. On the other hand, the impact of milk prices on intensification is less obvious. Variables related to pasture improvement (quantity of milk per unit of pasture and amount of investment in pasture improvement) show significant impacts of rising milk prices, but the variables related to cattle productivity (quantity of milk per unit of milk cattle and amount of investment in increasing cattle productivity) are less sensitive to price fluctuations. Results for quantity of milk per unit of pasture and stocking density show an increase with rising milk price.

[23] 1 US$ ~ 2 Brazilian Reais = 200 centavos

For an additional centavo per litre of milk, quantity of milk increased by 0.16 litre per unit of pasture and the stocking density increased by 0.19 cattle per hectare. As argued before, a higher stocking density may reflect more efficient utilization of cattle and pasture resources. On the other hand, very high stocking densities could lead to depletion of the fertility of the pasture (Walker, et al., 2000). Given stocking rates of 2 head per hectare on newly established pasture (White, et al., 2001), which declines over time without intensive management (Serrão and Homma, 1993), the average stocking rate of 2.54 in 2005 (Table 8) in the study area could prove to be unsustainable in the long run. Using only the reduced panel, the log of amount of investment to improve pasture productivity is significant but negative. This highlights the importance of defining intensification. The principal component constructed combining information from various measures of intensification is insignificant. One of the reasons behind the significance of the pasture-related intensification measures (vis-à-vis the milk-related) could be that use of supplemental feed and vitamins for the cattle herd was relatively common in the sample (refer to Table 7 with 93% of the farmers reporting that they provided supplemental feed to the herd, while it was relatively small in previous years) and has less variation in the data as compared to the pasture-intensification variables.

Farmers owning less land engage in lower levels of both intensification and extensification[24]. In separate analysis of the data, these farmers were found to be more engaged in agriculture of annual and perennial crops than pastures, thus less involved in allocating resources to pasture management. Farmers having lived on a lot for a longer period of time had a lower proportion of the lot devoted to pasture. One of the explanations for frontier migration of farmers is based on myopic clearing of forest on the lot without any consideration for long run pasture productivity (Campari, 2005). Given that, it seems likely that those farmers who lived on the same lot for a longer period have been judicious in clearing forest to create more pasture. There is weak evidence in favor of the fact that wealthier farmers (using the proxy of vehicle ownership) devote more resources to both extensification and intensification, though it is possible that extensive pastures helped them amass wealth that is being utilized in intensification, a hypothesis that will be tested later in the paper. In all the models in Table 11 & 12 (except for quantity of milk per cattle unit and stocking density for the reduced panel), a joint of F-test rejected the hypothesis that wealth indicators (lot size and vehicle ownership) did not matter for pasture management. Previous studies in the study area in particular (Caviglia-Harris, 2005) and the Amazon in general (Pacheco, 2005, Walker, et al., 2002) found that wealthy farmers deforest more.

[24] Since lot size was highly correlated with area in pasture (correlation coefficient = 0.89), the variable was created based on the time of land allocation and the municipality. Farmers in the municipalities of Ouro Preto, Vale do Paraíso, Nova União, and Teixeirópolis were allotted lots on an average of 100 hectares, while those in Mirante da Serra, and Urupá were allotted much smaller lots. This is correlated with lot size but less with land in pasture.

The estimation did not provide any evidence on the role of labor constraints on extensification and/or intensification decisions, as family size, average age of household heads and dummy for hired labor were insignificant across all the models. While distance to the town of Ouro Preto is not significant, there is weak evidence that intensification activities are higher among farmers living further from the municipal towns.

3.8.3. Fixed effects estimation (endogenous milk price):

While the rationale behind using the 3SLS models was that farmers may jointly make decisions regarding extensification and intensification, the concern driving these set of estimations relates to whether individual unobserved heterogeneity is the principal driver of pasture management decisions. To control for that, I use fixed estimation strategies designed to control for the unobserved heterogeneity (Wooldridge, 2001). Noting that milk price had significant explanatory power in (2), I also test if treating milk price as endogenous in the fixed effects model lead to any efficiency gains compared to the un-instrumented model. Based on results from the Hausman test that indicates whether the instrumented model is more efficient, I specify in the results if milk price is treated as endogenous or not.

Using notation that is consistent with equation (2), this model is represented as:

$$E_{it} = \alpha_{it}^{m} + \beta_m . p_{it} + \gamma_m . X_{it} + \theta_i + \varepsilon_{it}^{m}$$

$$\overline{E}_i = \overline{\alpha}_i^{m} + \beta_m . \overline{p}_i + \gamma_m . \overline{X}_i + \theta_i + \overline{\varepsilon}_i^{m}$$

$$E_{it} - \overline{E}_i = (\alpha_{it}^{m} - \overline{\alpha}_i^{m}) + \beta_m . (p_{it} - \overline{p}_i) + \gamma_m . (X_{it} - \overline{X}_i) + (\varepsilon_{it}^{m} - \overline{\varepsilon}_i^{m}) \quad (2)$$

Where m = extensification and intensification activities. Note that the individual specific heterogeneity (θ) is removed in equation (2) due to the time-demeaning.

In tables 3.15 & 3.16, the results from the fixed effects models are presented for the 'balanced panel' and 'reduced panel' respectively. The impact of milk price on extensification represented by percent area of land owned in pasture is significant. 1 centavos increase in milk price leads to a roughly 4% increase in percent of land devoted to pasture. Compared to previous results, the intensification indicators are consistently positive and much more significant across all the different measures. The effect of lot size on intensification measures is much more pronounced than before – farmers with smaller lots are found to intensify more. Those who have lived on the lot longer reported to make more investments improving productivity of both pasture and cattle. On the contrary, there is weak evidence of lower milk output per unit of pasture or cow. I conjecture that the increased investments may have been driven by the decreasing marginal outputs from pasture and the herd. There is no evidence on how labor constraints affect intensification or extensification outcomes, except that farmers who reported making investments to increase productivity reported to hire more labor. Part of

the pasture intensification process involves labor intensive activities like tilling, weeding and applying fertilizers and those effects could be causing the demand for hired labor. Combining the lot size variable with vehicle ownership, there is no discernible pattern in pasture management according to the wealth of the farmer, except significantly higher investments in pasture and cattle productivity. Membership in farmer associations that was found to have a significant impact on agricultural land use choices of farmers in a separate analysis seems to have little impact on pasture management. Though not shown in the results, whether farmers received government credit to invest in livestock did not seem to affect pasture or herd management.

Summarizing the results from models (1) – (3), there is strong evidence in favor of market expansion affecting pasture management decisions through the price of milk. However, higher milk price does not have unambiguous results either in favor of extensification or intensification. Supporting the analytical results from the theoretical model, farmers respond to higher milk prices by both extensifying and intensifying. Farmers living on larger lots engage more in extensification and less in intensification than those in smaller lots, pointing to the importance to stronger environmental legislation limiting farmers on the amount of deforestation on their lots. Farmers who have occupied their lots for longer time tend to have lower percent of land in pasture (significance in SUR and 3SLS model only). These farmers also have a lower stocking density on their lot, and have undertaken investments to improve pasture and cattle

productivity (Fixed effects model). Reflecting on the turnover hypothesis that associates mismanaged deforestation and pasture creation with higher propensity of frontier migration, these farmers probably have managed their land better. None of the demographic variables have strong explanatory power in these estimations. Farmers living closer to the town of Ouro Preto have converted much more land into pasture, supporting the fact that lots closer to road networks are more prone to deforestation (Pfaff, 2007).

3.8.4. Dynamic models with lagged price of milk:

Farmers land use decisions are essentially dynamic in nature (Andersen, et al., 2002), based on resource constraints, past investments as well as expectations about the future. In the following set of estimations, I use lagged values of price of milk and amount of forest on the lot. In the previous model, the price of milk and the management choices were contemporaneous in the sense that all the variables corresponded to the same survey year. Instead, in the following model, I introduce milk price from the previous period to check if the higher price for milk in the past affected future pasture management. I also introduce a lagged variable for forest that reflects the stock of land that a farmer had for clearing at the beginning of each period, in order to examine the conjecture in the previous models that farmers with land constraints on clearing and

establishing more pasture would be forced to focus more on intensification. The estimated model can be written as

Extensification: $E_{it} = \alpha_e + \beta_e . p_{i,t-1} + \gamma_e . X_{it} + \varepsilon_{it}^e$

Intensification: $I_{it} = \alpha_I + \beta_I . p_{i,t-1} + \gamma_I . X_{it} + \varepsilon_{it}^I$ (4)

As before, the correlation of the error terms between the two equations drives the joint estimation of the equations as a system.

Table 3.17 and 3.18 contains results from this set of estimations. I find strong evidence that increase in milk price in the previous period has a positive impact on extensification, but a relatively weak impact on intensification decisions (only quantity of milk per unit of pasture is significant across the two samples). Using these results, it is possible to test whether forest scarcity forces farmers to focus on intensification (White, et al., 2001). There is weak evidence that farmers with lower stock of remnant forest at the beginning of a period tend to focus more on intensification (from indicators of quantity of milk per unit of pasture and investment in improving productivity of cattle). Government credit has the intended effect by increasing investments in improving pasture productivity, but unlike the proposition of (Bulte, et al., 2007), there is no evidence that the credit has prompted extensification. It is worth mentioning that farmers reported to have been receiving the government credit only for the past 5 years or so.

Also, there has been increased awareness among farmers of increased vigilance by IBAMA, the Brazilian Environmental Law Enforcement Agency, to prevent deforestation. These two factors combined could have discouraged farmers to engage in forest clearing. The time dummy is insignificant for the extensification variables, while intensification significantly increased between 2000 and 2005 as observed from the farmers' responses on investments in cattle and pasture productivity. Thus even using past values of milk prices that reduces the endogeneity concerns present in the 3SLS and fixed effects models, I find evidence that milk price continues to have power in explaining pasture management choices of farmers.

3.9 Impact of intensification on deforestation and migration

From a long term policy perspective, it is of interest to examine if intensification actually achieves the objectives of reducing deforestation, pasture creation and frontier migration. Using a dummy if a farmer reported to have invested in improving pasture and/or cattle productivity, I examine what impact intensification had on changes in deforestation, creation of new pastures and migration (changes in members of adult members in the family). The treatment effects model considers the effect of an endogenously chosen binary treatment on another endogenous continuous variable, conditional on two sets of independent variables (Maddala, 1983). Here, intensification decision of a farmer is conceived of as a 'treatment', and its effect on deforestation,

pasture creation and migration is examined. Assume that (C_i) denotes the change in the variable of interest – forest, pasture and migration (using reduction in adult family members as a proxy). Also, $(.I_i)$ denotes a dummy for intensification, which is '1' if a farmer reported to have made investments in improving pasture and/or cattle productivity. The model can be written as:

$$C_i = \alpha_i + \beta.X_i + \rho.I_i + \varepsilon_i$$

The binary decision to adopt the treatment $(.I_i)$ is modeled as the outcome of an unobserved latent variable, $(.I_i^*)$. It is assumed that $(.I_i^*)$ is a linear function of the exogenous covariates (w_i) and a random component (u_i) . Specifically,

$$I_i^* = \lambda.w_i + u_i$$

Such that the observed decision is given by

$$\begin{matrix} I_i = 1 \\ I_i = 0 \end{matrix} \quad \text{if} \quad \begin{matrix} I_i^* > 0 \\ I_i \leq 0 \end{matrix}$$

And the error terms (ε_i, u_i) are assumed to be bivariate normal with mean 0 and covariance $\sigma^2\rho$.

Table 3.19 contains the result for this set of estimations. In the first stage, a probit model is estimated to determine the probability of a farmer investing in pasture/cattle

improvement. In the second stage, the predicted value of intensification is regressed on deforestation, new pasture formation and migration with a set of control variables. The equations are estimated simultaneously using maximum likelihood estimation methods. The term indicating the correlation between the error terms (rho) of the equations in the two stages is significant across all the different models estimated, validating the use of the 'treatment selection' procedure. I find evidence that farmers who intensified deforested less on their lot. However, those who intensified also created more pasture on their lot. It is apparently confusing to compare the evidence of reduced deforestation with increase in pasture area. Note that the data on land use comes from values reported by farmers. If farmers were able to re-use degraded or unused pastures following more active pasture management, then that maybe reflected in a higher number for land in pasture in the current period, though no active deforestation to create new pastures took place. I also look at how intensification has affected the change in family structure, keeping in mind the 'turnover hypothesis' in the Amazon (Campari, 2005), which postulates that decline in pasture productivity forces farmers to sell or abandon their land and move further into frontier to establish new settlements. I find evidence that adult members in the family of farmers who intensify more have an increase in the number of adult members in the household over time. I do not have detailed information on whether this increase is due to members of the extended family beginning to live on the lot. However, if there was evidence for out-migration, then there would have been support for the theory of frontier migration. Given that limited information on the context of

migration is available, the results can be generally interpreted as farmers who intensify more also seem to have more stable families.

3.10 Conclusion

In this paper, I develop a theoretical model to examine how market expansion could affect pasture management outcomes, and provide a series of empirical estimations using survey information from a panel of farmers in the Brazilian Amazon. While the dominance of pasture and cattle ranching among small farmers in the Amazon continues, policy makers need to evaluate strategies to ensure that this system of land use is environmentally and economically sustainable. While technological and agronomic research provides various solutions to increase marginal productivity of pasture and cattle to ensure non-declining yields over time, its impact on intensification and/or extensification choices small farmers make is ambiguous. This result follows from the theoretical model, and is supported by the empirical results.

It is important to note that intensification of pasture management involves a complex set of activities, often complimentary to one another. As a result, empirical investigation of intensification is data-intensive. Also, there is a gestation period for some of these activities to provide perceptible difference in outcomes necessitating in-depth soil surveys and forage yields to judge the efficacy of particular activities. The data used

in the analysis has the important time dimension to analyze the dynamics of the systems, but the results are sensitive to alternative definitions of intensification. Future research should be focused on the interplay between the different dimensions of intensification to derive cumulative measures more amenable to empirical analyses.

From a policy perspective, increased competition among milk plants seems to affect both intensification and extensification of the (farmers) producers in the systems. The study area is endowed with uncharacteristically fertile soils relative to other settlements in the Amazon. Similar research in other areas is needed to infer on the efficacy of improved markets to encourage farmers to practice more intensive pasture management. But market expansion without enforcement of strong environmental regulations may not achieve the desired goal of improving the welfare of frontier population and reducing deforestation in the Amazon.

3.11 Appendix

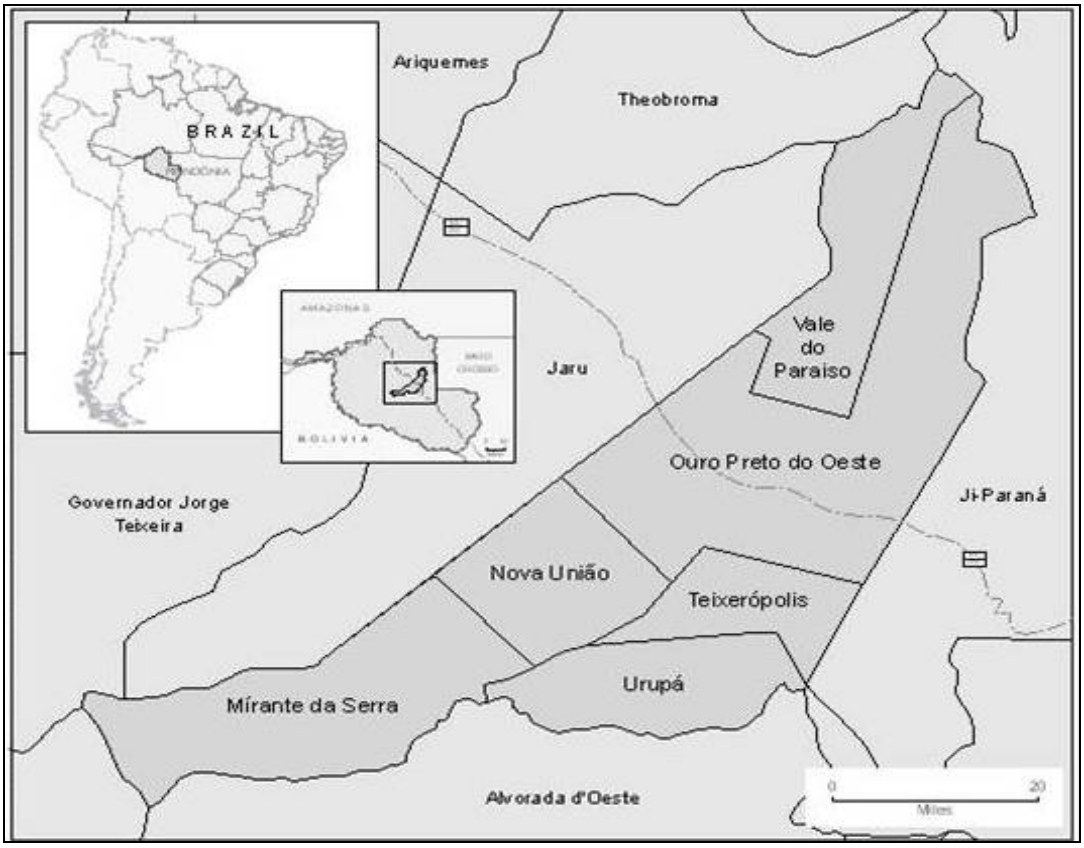


Figure 3.1 Ouro Preto do Oeste settlement in Rondonia, Brazil.
The settlement is comprised of 6 municipalities –
Ouro Preto do Oeste, Vale do Paraíso, Nova União, Teixeirópolis, Mirante da Serra and Urupá

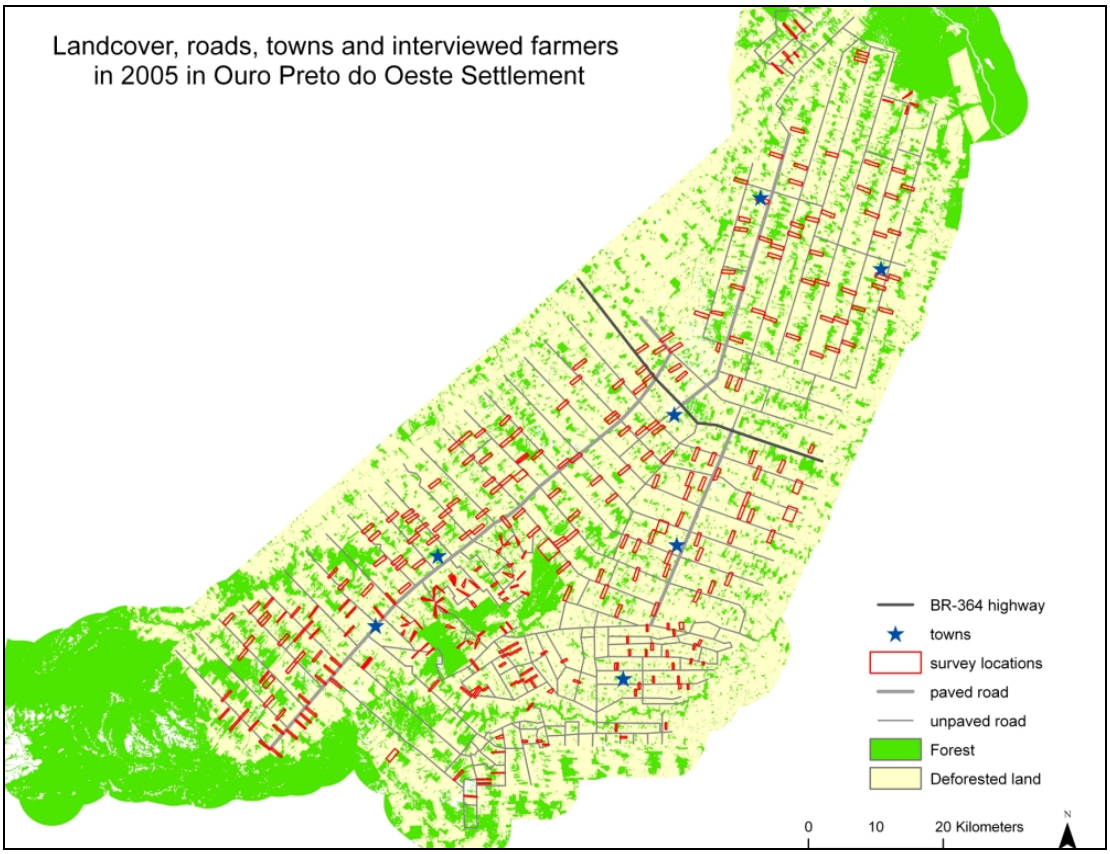


Figure 3.2 Study area indicating spatial data on landcover, towns, roads and farmers included in the survey in 2005

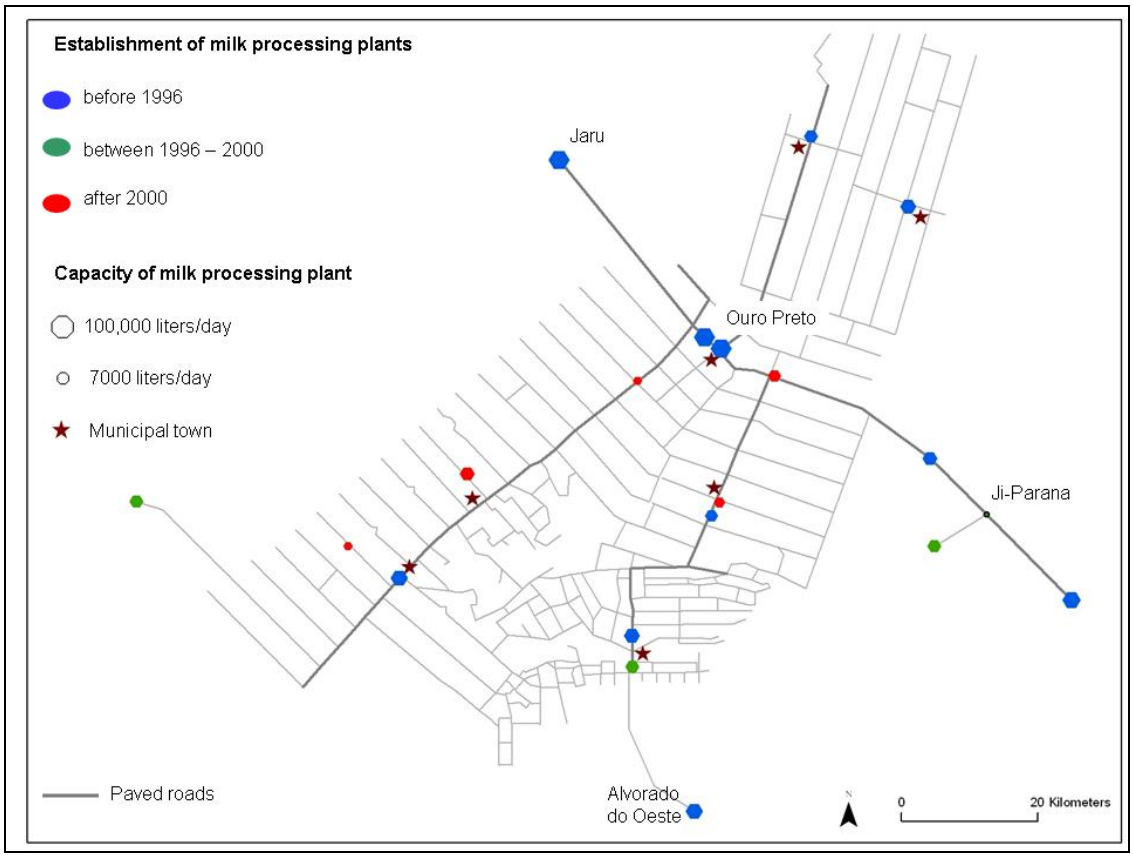


Figure 3.3 Evolution of milk processing plants in the study area

The increase in milk processing facilities in the Ouro Preto do Oeste region over the study period. While the initial plants (indicated by blue) were established in the main urban centers of Ouro Preto do Oeste, Jaru and Ji-Parana along the main paved highway (BR-364), the recent ones have been setup within the study area. This has increased the number of plants collecting milk along each secondary road, thus increasing competition among the plants. Note that the new plants are relatively smaller in size (indicated by green and red)

Table 3.1. Change in area in pasture for states in the Legal Amazon 1996-2006

	1996		2006	
	Area (hectares)	% of total area	Area (hectares)	% of total area
Rondônia	2922068	33	5064262	58
Acre	614214	19	1032430	27
Amazonas	528913	16	1836534	24
Roraima	1542566	52	806557	43
Para	7454527	33	13167855	48
Amapá	244978	35	432034	31
Tocantins	11078151	66	10290857	61
Maranhão	4671797	46	5583822	48
Mato Grosso	21452064	43	22733315	48

Source: IBGE, Censo Agropecuário 2006

Table 3.2. Change in heads of cattle for states in the Legal Amazon 1990-2006

	1990	2006	% change
Rondônia	1718697	11484162	568
Acre	400085	2452915	513
Amazonas	637299	1243358	95
Roraima	0	508600	-
Para	6182090	17501678	183
Amapá	69619	109081	57
Tocantins	4309160	7760590	80
Maranhão	3396678	6037990	78
Mato Grosso	9041258	26036627	188

Source: IBGE, Censo Agropecuário 2006

Table 3.3 Change in total cattle population in Rondônia and study region from 1990-2006

	1990	1996	2000	2006
Ouro Preto do Oeste	179922	316175	259615	357020
Nova União	-	-	84159	125556
Mirante da Serra	-	35590	55466	106692
Teixeirópolis	-	-	60696	84799
Urupá	-	55166	79722	156005
Vale do Paraíso	-	66147	95591	159341
Jaru *	119779	197285	285104	520925
Ji-Paraná *	109610	204525	318748	444058
Rondônia	1718697	3937291	5664320	11484162

Source: IBGE, Pesquisa Pecuária Municipal

Table 3.4 Change in milk cattle population in Rondônia and study region from 1990-2005

	1990	1996	2000	2006
Ouro Preto do Oeste	35984	51232	43434	78094
Nova União	-	-	12110	29985
Mirante da Serra	-	5628	8769	22203
Teixeirópolis	-	-	9754	19384
Urupá	-	10394	4233	32304
Vale do Paraíso	-	11242	5621	30230
Jaru *	23955	31684	44927	83952
Ji-Paraná *	21922	26201	40832	54248
Rondônia	263340	340023	459182	947401

Source: IBGE, Pesquisa Pecuária Municipal

These tables show changes in the cattle population in the six municipalities comprising the study area.
* Figures for the adjoining municipalities are also provided to emphasize the growing importance of cattle ranching (and especially milk production) in the region.
- indicates that data was not available for the year or the municipality was not designated in that year

Table 3.5 Profile of milk plants collecting milk from farmers living in the Ouro Preto do Oeste region

Laticinio name	Municipality where plant located	Average distance travelled to collect milk	Year plant started	Number of farmers selling milk in			Capacity of milk plant ('000 litres)			Number of workers	Number of trucks used to collect milk	Percentage of farmers selling following amount in 2005 (in litres)				
				2005	2000	1996	2005	2000	1996			1-10	10-30	30-50	50-100	>100
Parmalat	Ouro Preto	210	1989	280	890	950	105	95	80	80	35	5	5	20	30	40
Tradicao	Ji-Paraná	75	1989	950	880	750	55	48	40	34	23	5	10	35	30	20
Mutilac	Alvorado do Oeste	100	1991	700	900	1000	36.5	42.5	32.5	35	6	10	40	20	20	10
Samira	Ouro Preto	180	1991	1000	900	750	85	75	60	65	31	10	15	30	30	15
Italac	Jaru	80	1992	1500	1470	1280	100	90	65	65	21	10	15	25	30	20
Monte Verde	Mirante da Serra	100	1992	950	700	400	42.5	28.5	17.5	40	15	5	10	35	30	20
Ourominas	Vale do Paraiso	40	1992	670	600		32.5	29	24	30	12	10	30	25	20	15
Tradicao	Urupá	50	1992	868	950	840	33	30	30	19	11	15	30	25	20	10
Flor de Rondonia	Presidente Medici	160	1993	1100	1200	600	55	45	35	50	16	5	20	25	40	10
Beira Rio	Jiparana	50	1994	480	350	200	25.5	26	11.5	34	10	10	15	30	40	5
Tradicao	Teixeirópolis	40	1994	338	280	250	17.5	19.5	20	14	9	15	30	25	20	10
Tradicao	Vale do Paraiso	45	1994	370	500	400	20.5	20.5	16.5	14	7	10	30	35	15	10
Italac	Tarilandia	60	1997	570	500		21	16	13.5	21	10	15	30	25	20	10
Jipalac	Ji-Paraná	75	1997	450	350		19.5	23		16	8	10	35	35	15	5
Favo de mel	Urupa	25	1999	320	250		19	16.5		12	8	15	25	30	25	5
Costa e Costa	Ouro Preto	45	2000	320	230		16	14.75		16	9	20	30	30	15	5
Italac	Nova União	60	2001	600			24			17	13	15	30	25	20	10
Santa Clara	Ouro Preto	45	2002	126			8.5			12	6	15	30	30	20	5
Miralac	Mirante da Serra	160	2003	250			7			7	3	20	35	25	15	5
Vitalli	Teixeirópolis	50	2003	240			13.25			15	6	15	30	15	17	23

Table 3.6. Reasons cited by farmers for choosing milk plants

	Reasons for choosing milk plant in the beginning	Reasons for switching selling milk to other plant
Only option	69	0
Better price	7	37
Knows owner of plant	5	8
Knows driver of the milk truck	13	32
Neighbor	4	21
Financial assistance from plant	1	1

In the 2006 survey, farmers were asked specific questions related to the criteria based on which they choose to sell to particular milk plants. Questions were asked both with respect to the time when they began selling milk, and then related to the time when they switched milk plants. Such qualitative information provides a way to compare how the preferences of farmers changed as the milk market expanded.

Table 3.7 Types of intensification activities and investment in milk quality reported by farmers

	2005	2000	1996
Cattle investment			
Better genetic variety of cows	10	2	1
Food supplements, vitamins	88	12	0
Pasture investment			
Planted better adapted grass	15	0	0
Tilled the land with equipment	25	1	0
Build fence for rotational system	9	4	2
Used fertilizer and herbicide	4	1	2
Rocadeira	10	2	0
Milk quality *			
Corral infrastructure	18	4	2
Mechanized milking equipment	3	1	1

* Corral and mechanized milking equipment does not fall under intensification activities but are more like investment to improve milk quality. The available information on reported amounts invested in these activities is lumped and cannot be separated for individual activities.

Table 3.8 Comparing means of variables across time periods

	1996		2000		2005	
	mean	st. dev.	mean	st. dev.	mean	st. dev.
Area in crops (hectare) [23]	7.42	6.72	6.74	7.43	4.59	5.42
Area in forest (hectare) [123]	20.22	23.91	15.23	18.78	10.44	17.28
Area in pasture (hectare) [23]	47.18	39.31	44.01	31.17	59.33	57.97
Years living on lot [123]	11.91	6.70	15.43	7.18	25.53	6.17
Family size [1]	9.03	6.39	7.55	5.80	7.70	5.27
Value of vehicles owned [23]	1472.60	2912.98	1554.79	2378.15	7692.72	13291.59
Expenditure on hired labor [23]	183.08	879.16	123.88	251.28	553.07	1104.13
Price of milk/litre [13]	0.15	0.08	0.19	0.10	0.26	0.09
Quantity of milk sold [13]	46.87	54.87	95.86	86.89	85.45	79.73
Income from milk [13]	3335.73	4040.18	6549.00	7712.42	6312.41	7045.04
Income from beef [13]	-	-	2545.33	6622.95	5947.54	21379.98
Income from off-farm	2149.67	6070.69	3533.55	6858.27	4292.43	5221.83
Total cash income [13]	11119.61	12878.94	17681.07	18115.86	18956.89	24609.05
Credit used for livestock	561.64	5062.33	424.66	2012.33	4125.84	24489.10
Investment in milk production [23]	713.01	8491.29	720.07	8491.09	2975.59	10740.44
Investment in pasture improvement [23]	0.00	0.00	0.00	0.00	1141.02	4928.87
Herd size [13]	77.28	87.17	98.92	96.85	98.51	96.12
Stocking density [1]	1.80	1.61	2.52	2.28	2.10	2.54
Distance to 4 nearest milk plants [23]	39.71	14.09	34.87	12.44	27.33	9.54
Number of plants buying milk [123]	1.96	0.74	3.49	0.72	5.12	1.21

These numbers are based on the panel of 146 farmers.
1, 2, 3 indicate that the variable is significantly different between the periods 1996-2000, 2000-2005, 1996-2005 respectively;
All income and price figures are in constant 2000 Reais

Table 3.9 Probit estimation for completeness of labor market (dependent variable: dummy if farmer hired labor): Full sample

	2005			2000			1996		
	df/dx	st error	p-val	df/dx	st error	p-val	df/dx	st error	p-val
Lot size (hectares)	0.004	0.002	0.042	0.003	0.001	0.013	-0.001	0.001	0.483
Land in agriculture (hectares)	0.007	0.006	0.256	-0.004	0.003	0.174	0.005	0.006	0.392
Land in pasture (hectares)	-0.005	0.002	0.023	-0.004	0.001	0.003	0.003	0.002	0.078
Years living on lot	0.002	0.004	0.640	-0.001	0.003	0.700	-0.002	0.006	0.748
Average age of household heads	-0.001	0.002	0.589	-0.001	0.001	0.513	**-0.007**	0.003	0.045
Family size	**-0.024**	0.007	0.001	-0.001	0.004	0.763	**-0.029**	0.008	0.002
Ratio of men to family size	-0.308	0.191	0.108	**-0.258***	0.106	0.018	-0.079	0.180	0.658
Log of cattle herd	0.074	0.026	0.004	0.156	0.032	0.000	0.003	0.030	0.914
Log of value of vehicles owned	0.024	0.008	0.001	-0.007	0.005	0.139	0.000	0.009	0.990
Log of GIS distance to nearest town	-0.050	0.027	0.062	-0.064	0.031	0.032	0.010	0.048	0.835
Soil quality	-0.048	0.041	0.246	-0.008	0.016	0.610	0.010	0.026	0.704
Dummy for association membership	0.067	0.058	0.248	-0.038	0.038	0.309	0.164	0.071	0.018
N		302			193			196	
Pseudo R-Sq		0.113			0.256			0.169	
Wald Chi-sq		40.51			38.75			20.92	
Prob > Chi-sq		0.001			<0.001			0.052	
Joint significance of family variables #									
Prob > Chi-sq		0.004			0.095			0.004	

* For 2000, the variable ratio of men to family size is insignificant, but ratio of adult members in the family is significant.
# Joint test of significance of average age of household heads, family size and ratio of men to family size

Table 3.10 Probit estimation for completeness of labor market (dependent variable: dummy if farmer hired labor): Balanced panel

	2005			2000			1996		
	df/dx	st error	p-val	df/dx	st error	p-val	df/dx	st error	p-val
Lot size (hectares)	0.005	0.002	0.054	0.003	0.001	0.015	0.000	0.001	0.943
Land in agriculture (hectares)	0.001	0.009	0.939	-0.006	0.004	0.130	0.004	0.006	0.492
Land in pasture (hectares)	-0.007	0.003	0.028	-0.005	0.002	0.009	0.002	0.002	0.248
Years living on lot	0.002	0.006	0.713	-0.006	0.005	0.240	0.002	0.006	0.758
Average age of household heads	0.000	0.004	0.966	-0.001	0.002	0.508	**-0.011**	0.003	0.001
Family size	**-0.023**	0.010	0.016	0.002	0.005	0.654	**-0.027**	0.008	0.006
Ration of men to family size	-0.192	0.270	0.480	-0.207 *	0.159	0.202	0.085	0.189	0.650
Log of cattle herd	0.095	0.040	0.020	0.203	0.048	0.000	-0.019	0.030	0.522
Log of value of vehicles owned	0.013	0.012	0.287	-0.013	0.007	0.083	0.002	0.009	0.839
Log of GIS distance to nearest town	-0.058	0.031	0.063	-0.116	0.051	0.022	-0.032	0.054	0.556
Soil quality	-0.059	0.054	0.274	-0.012	0.023	0.589	0.017	0.026	0.529
Dummy for association membership	0.042	0.086	0.627	-0.063	0.058	0.271	0.074	0.076	0.308
N		146			146			146	
Pseudo R-Sq		0.115			0.273			0.226	
Wald Chi-sq		18.69			37.63			34.71	
Prob > Chi-sq		0.093			<0.001			<0.001	
Joint significance of family variables #									
Prob > Chi-sq		0.096			0.458			<0.001	

Joint test of significance of average age of household heads, family size and ratio of men to family size

Table 3.11 Seemingly Unrelated Regression for impact of market expansion on extensification and intensification (Balanced panel)

	Extensification			Intensification								
	Percent of lot in pasture			Quantity of milk per unit of pasture			Quantity of milk per unit of milk cattle			Stocking density		
	coeff	*st error*	*p-value*	*coeff*	*st error*	*p-value*	*coeff*	*st error*	*p-value*	*coeff*	*st error*	*p-value*
intercept	84.655	10.885	0.000	2.213	1.112	0.047	3.918	1.457	0.007	2.666	1.149	0.020
New municipality	-8.874	2.825	0.002									
Lot size (hectares)				-0.006	0.002	0.004	-0.006	0.003	0.037	-0.003	0.002	0.133
Years living on lot	-0.439	0.151	0.004	-0.005	0.016	0.751	0.022	0.021	0.291	-0.031	0.017	0.063
Family size	-0.242	0.174	0.164	-0.020	0.019	0.281	0.017	0.024	0.490	0.024	0.019	0.220
Average age of hhd heads	0.109	0.079	0.169	0.000	0.008	0.961	0.010	0.011	0.371	-0.007	0.009	0.454
Dummy if migrated from South	3.391	2.442	0.165	0.149	0.256	0.562	0.285	0.336	0.396	0.059	0.265	0.823
Log of value of vehicles owned	0.733	0.257	0.004	0.056	0.028	0.044	0.026	0.037	0.477	0.021	0.029	0.474
Dummy for hired labor	0.809	2.165	0.709	-0.076	0.232	0.742	-0.120	0.304	0.693	0.017	0.240	0.943
Log of distance to Ouro Preto town	-1.059	2.746	0.700	0.316	0.267	0.236	-0.267	0.350	0.446	0.282	0.276	0.306
Elevation	-0.003	0.023	0.906	-0.003	0.002	0.212	0.000	0.003	0.897	-0.002	0.003	0.347
Soil quality	-1.790	1.331	0.179	-0.316	0.137	0.021	-0.130	0.180	0.470	-0.210	0.142	0.139
Time dummy 1996-2000	11.037	4.596	0.016	-0.298	0.492	0.544	0.598	0.645	0.354	0.043	0.509	0.932
Time dummy 2000-2005	5.310	2.802	0.058	0.559	0.300	0.062	0.612	0.393	0.119	0.537	0.310	0.083
Dummy for association member	-9.161	1.947	0.000	0.276	0.207	0.184	0.546	0.272	0.045	0.268	0.214	0.211
Number of plants	1.578	1.090	0.148	0.125	0.116	0.284	-0.219	0.152	0.150	0.133	0.120	0.268
Average distance to 4 nearest plants	-0.387	0.132	0.003	-0.020	0.014	0.166	-0.010	0.018	0.580	-0.017	0.015	0.253
N		438			438			438			438	
Adjusted R-sq		0.335			0.098			0.052			0.057	
Chi-sq		221.35			48			24.48			26.45	
Pr > Chi-sq		0.000			0			0.057			0.034	

Table 3.12 Seemingly Unrelated Regression for impact of market expansion on extensification and intensification (Reduced panel)

	Extensification		Intensification											
	Percent of lot in pasture		Quantity of milk per unit of pasture		Quantity of milk per unit of milk cattle		Stocking density		log of investment in milk		log of investment in pasture		Principal Component	
	coeff	p-val	coeff	p-val	coeff	p-val	coeff	p-val	coeff	p-val	coeff	p-val	coeff	p-val
intercept	99.481	0.000	2.326	0.103	4.736	0.023	2.587	0.047	1.862	0.096	2.247	0.105	2.548	0.019
New municipality	-13.993	0.000												
Lot size (hectares)			-0.003	0.292	-0.006	0.094	-0.002	0.330	0.009	0.000	0.012	0.000	0.008	0.000
Years living on lot	-0.765	0.000	-0.023	0.255	0.009	0.753	-0.038	0.043	-0.023	0.153	-0.020	0.309	-0.026	0.098
Family size	-0.271	0.161	-0.018	0.420	0.007	0.815	0.039	0.052	-0.009	0.615	-0.015	0.471	0.006	0.733
Average age of hhd heads	0.097	0.308	0.006	0.543	-0.004	0.811	0.003	0.765	-0.008	0.361	-0.015	0.147	-0.010	0.210
Dummy if migrated from South	1.740	0.548	-0.078	0.812	0.175	0.714	0.188	0.529	0.079	0.757	-0.148	0.642	-0.104	0.677
Log of value of vehicles owned	0.264	0.378	0.064	0.061	0.011	0.818	0.016	0.605	-0.020	0.455	0.045	0.172	-0.007	0.799
Dummy for hired labor	0.508	0.851	0.179	0.557	-0.259	0.563	0.176	0.528	0.328	0.171	0.222	0.454	0.376	0.105
Log of distance to Ouro Preto town	-5.731	0.097	0.104	0.775	-0.237	0.655	0.052	0.877	-0.591	0.038	-0.455	0.198	-0.660	0.017
Elevation	0.023	0.375	-0.005	0.121	0.002	0.661	-0.004	0.151	0.003	0.141	-0.006	0.040	0.000	0.857
Soil quality	-1.622	0.323	-0.171	0.323	-0.199	0.431	-0.096	0.544	-0.041	0.761	-0.065	0.697	0.036	0.786
Time dummy 1996-2000	20.640	0.000	-0.534	0.374	1.097	0.212	-0.198	0.719	7.175	0.000	3.753	0.000	1.308	0.004
Time dummy 2000-2005	9.939	0.002	0.510	0.165	0.529	0.326	0.529	0.116	0.324	0.262	0.309	0.387	0.299	0.284
Dummy for association member	-4.661	0.037	-0.014	0.956	0.654	0.076	-0.023	0.921	-0.091	0.644	0.226	0.357	0.135	0.481
Number of plants	1.226	0.318	0.252	0.068	-0.217	0.283	0.269	0.033	-0.049	0.651	-0.085	0.525	-0.091	0.386
Average distance to 4 nearest plants	-0.299	0.075	-0.013	0.502	-0.013	0.641	-0.018	0.288	0.000	0.986	0.031	0.096	0.004	0.796
N	285		285		285		285		285		285		285	
Adjusted R-sq	0.401		0.108		0.041		0.108		0.808		0.427		0.191	
Chi-sq	191.66		34.86		12.44		34.59		1200.81		213.17		67.2	
Pr > Chi-sq	0.000		0.002		0.645		0.003		0.000		0.000		0.000	

Table 3.13 3SLS estimation of pooled data with endogenous milk price (balanced panel)

	Extensification			Intensification								
	Percent of lot in pasture			Quantity of milk per unit of pasture			Quantity of milk per unit of milk cattle			Stocking density		
	coeff	*st error*	*p-value*	*coeff*	*st error*	*p-value*	*coeff*	*st error*	*p-value*	*coeff*	*st error*	*p-value*
intercept	35.563	29.444	0.228	-0.688	2.062	0.739	5.102	3.122	0.103	-0.028	2.350	0.991
New municipality	-8.807	4.151	0.035									
Lot size (hectares) *				-0.006	0.002	0.002	-0.003	0.003	0.244	-0.004	0.002	0.073
Years living on lot	-0.447	0.225	0.047	-0.005	0.016	0.767	0.018	0.024	0.460	-0.030	0.018	0.105
Family size	-0.241	0.259	0.354	-0.020	0.019	0.287	0.016	0.028	0.561	0.024	0.021	0.264
Average age of hhd heads	0.113	0.118	0.337	0.001	0.008	0.946	0.010	0.013	0.422	-0.006	0.010	0.508
Dummy if migrated from South	3.271	3.624	0.367	0.152	0.257	0.555	0.232	0.389	0.552	0.071	0.293	0.810
Log of value of vehicles owned	0.756	0.381	0.048	0.058	0.028	0.039	0.025	0.042	0.556	0.023	0.032	0.473
Dummy for hired labor	0.700	3.217	0.828	-0.075	0.233	0.748	-0.161	0.352	0.648	0.025	0.265	0.925
Log of distance to Ouro Preto town	-2.505	3.426	0.465	0.275	0.212	0.196	-0.486	0.321	0.132	0.261	0.242	0.282
Elevation	-0.006	0.034	0.864	-0.003	0.002	0.203	-0.001	0.004	0.767	-0.002	0.003	0.398
Soil quality	-1.797	1.979	0.364	-0.316	0.137	0.022	-0.131	0.208	0.531	-0.209	0.157	0.183
Time dummy for 2000	9.759	6.528	0.136	-0.334	0.471	0.479	0.393	0.715	0.582	0.027	0.537	0.960
Time dummy for 2005	4.543	3.984	0.255	0.538	0.287	0.062	0.487	0.436	0.265	0.528	0.328	0.108
Dummy for association member	-9.318	2.885	0.001	0.270	0.207	0.193	0.525	0.314	0.095	0.264	0.236	0.264
Milk price per litre (in cents)	270.938	106.773	0.012	16.103	7.649	0.036	-7.064	11.593	0.543	15.126	8.720	0.084
N		438			438			438			438	
Adj R-square		0.163			0.072			0.057			0.024	
F-value		7.08			3.4			1.95			1.56	
Pr < F		<0.001			<0.001			0.028			0.087	

Milk price is treated as an endogenous variable with instruments in the first stage regression being – number of milk plants that farmer could sell milk to, average distance to four nearest milk plants.

Table 3.13 (continued)

The results from the first stage regression are in the following table:

Dep var = milk price (in 2000 Reais)			
	coeff	*st error*	*p-value*
Intercept	0.183	0.020	<.0001
Number of milk plants to sell to	0.009	0.003	0.004
Average distance to 4 nearest milk plants	-0.001	0.000	0.004
N	438	F-val	15.5
Adj R-sq	0.06	Pr > F	0.001

Table 3.14 3SLS estimation of pooled data with endogenous milk price (reduced panel)

dependent variable	Extensification		Intensification											
	Percent of lot in pasture		Quantity of milk per unit of pasture		Quantity of milk per unit of milk cattle		Stocking density		Log of investment in milk		Log of investment in pasture		Principal component	
	coeff	*p-val*	*coeff*	*p-val*	*coeff*	*p-val*	*coeff*	*p-val*	*coeff*	*p-val*	*coeff*	*p-val*	*coeff*	*p-val*
intercept	66.039	0.009	-1.071	0.656	5.900	0.124	-1.370	0.596	2.360	0.226	5.254	0.051	3.691	0.063
New municipality	-14.024	0.001												
Lot size (hectares)			-0.003	0.240	-0.005	0.182	-0.003	0.313	0.009	<.0001	0.013	<.0001	0.008	<.0001
Years living on lot	-0.768	0.000	-0.022	0.282	0.007	0.832	-0.037	0.098	-0.023	0.162	-0.020	0.384	-0.026	0.120
Family size	-0.271	0.225	-0.018	0.416	0.008	0.816	0.038	0.104	-0.009	0.632	-0.015	0.531	0.006	0.747
Average age of hhd heads	0.098	0.372	0.006	0.560	-0.003	0.841	0.003	0.811	-0.008	0.382	-0.015	0.203	-0.010	0.254
Dummy if migrated from South	1.672	0.615	-0.053	0.872	0.124	0.812	0.214	0.543	0.072	0.787	-0.140	0.702	-0.117	0.664
Log of value of vehicles owned	0.265	0.444	0.064	0.062	0.010	0.855	0.017	0.647	-0.020	0.467	0.045	0.240	-0.007	0.802
Dummy for hired labor	0.491	0.875	0.184	0.549	-0.266	0.587	0.180	0.585	0.327	0.189	0.225	0.511	0.374	0.141
Log of distance to Ouro Preto town	-6.363	0.061	0.282	0.336	-0.530	0.256	0.207	0.511	-0.639	0.008	-0.342	0.294	-0.725	0.003
Elevation	0.021	0.467	-0.004	0.164	0.001	0.841	-0.003	0.279	0.003	0.166	-0.006	0.082	0.000	0.944
Soil quality	-1.569	0.403	-0.184	0.289	-0.178	0.520	-0.107	0.565	-0.038	0.787	-0.074	0.703	0.040	0.777
Time dummy for 2000	20.119	0.001	-0.385	0.505	0.844	0.359	-0.065	0.917	7.135	<.0001	3.842	<.0001	1.250	0.009
Time dummy for 2005	9.642	0.008	0.593	0.096	0.389	0.492	0.603	0.116	0.302	0.296	0.361	0.363	0.268	0.362
Dummy for association member	-4.659	0.071	-0.015	0.952	0.657	0.105	-0.024	0.929	-0.091	0.658	0.226	0.425	0.136	0.516
Milk price per litre (in cents)	166.750	0.030	16.398	0.030	-5.236	0.663	19.261	0.018	-2.371	0.698	-15.192	0.071	-5.561	0.371
N	285		285		285		285		285		285		285	
Adj R-square	0.314		0.065		0.023		0.053		0.712		0.339		0.129	
F-value	10.3		2.41		1.43		1.74		79.76		11.43		4.01	
Pr < F	<0.0001		0.003		0.138		0.048		<0.000		<0.001		<0.001	

Each of the intensification decisions are estimated as a system with the extensification variable and the endogenous price equation, assuming that the errors are correlated across the equations. Additional intensification variables come from the 2006 survey for which the sample size is reduced.

* Lot size is not used in the extensification equation as it is highly collinear with area in pasture. Instead percent of land owned devoted to pasture is used as the dependent variable for extensification, and lot size is dropped from the LHS.

First stage regression for milk price is similar to one presented with table 3.13.

Table 3.15 Fixed effects estimation for impact of milk price on extensification and intensification (balanced panel)

	Extensification			Intensification								
	Percent of lot in pasture #			Quantity of milk per unit of pasture #			Quantity of milk per cattle *			Stocking density *		
	Coeff.	*Std. error*	*p-val*	*Coeff.*	*Std. error*	*p-val*	*Coeff.*	*Std. error*	*p-val*	*Coeff.*	*Std. error*	*p-val*
Milk price per litre (in cents)	410.402	168.634	0.015	40.625	15.930	0.011	14.238	1.839	0.000	7.972	1.607	0.000
Lot size (hectares)				-0.004	0.006	0.532	-0.002	0.004	0.566	-0.009	0.003	0.005
Years living on lot	-0.050	0.392	0.899	-0.075	0.037	0.042	-0.007	0.021	0.736	-0.015	0.019	0.414
Family size	-0.541	0.399	0.175	-0.043	0.036	0.230	0.005	0.028	0.862	0.008	0.024	0.753
Average age of household heads	-1.551	1.356	0.253	-0.067	0.121	0.581	0.112	0.091	0.217	-0.028	0.079	0.723
Average age of hhd heads (Squared)	0.013	0.013	0.314	0.000	0.001	0.711	-0.001	0.001	0.252	0.000	0.001	0.840
Log of value of vehicles owned	0.127	0.566	0.822	0.005	0.051	0.925	0.009	0.039	0.812	0.008	0.034	0.826
Log of payment for hired labor	-1.247	0.928	0.179	-0.166	0.087	0.057	-0.076	0.050	0.126	-0.039	0.043	0.365
Dummy for association membership	0.979	5.918	0.869	0.094	0.527	0.858	0.421	0.415	0.311	0.273	0.362	0.451
Intercept	45.240	32.421	0.163	-1.175	2.988	0.694	-2.230	2.193	0.310	2.521	1.917	0.189
N		438			438			438			438	
Chi-Sq		1776.41			146.03			7.97 ~			4.07 ~	
Prob > Chi-Sq		0.000			0.000			0.000			0.000	
Hausman test for IV(FE) vs FE models												
Chi-Sq(1) at p=0.1 is 2.706		4.92			3.88			2.28			2.63	
Prob > Chi-Sq		0.766			0.867			0.971			0.955	

* A Hausman test is performed to test the efficiency of models with instrumented milk price against the non-instrumented model Based on $\chi^2_{0.1}(1) = 2.706$, the corresponding models in panels 3, 4 were estimated without using instruments for milk price.

~ Instead of Chi-Sq values, F-statistics are presented for these models

Milk price is treated as an endogenous variable with instruments in the first stage regression being – number of milk plants that farmer could sell milk to and average distance to four nearest milk plants.

Table 3.16 Fixed effects estimation for impact of milk price on extensification and intensification (reduced panel)

	Extensification		Intensification											
	Percent of lot in pasture #		Quantity of milk per unit of pasture #		Quantity of milk per cattle *		Stocking density #		Log of Investment in pasture *		Log of investment in cattle #		Principal components *	
	Coeff.	*p-val*	*Coeff.*	*p-val*	*Coeff.*	*p-val*	*Coeff.*	*p-val*	*Coeff.*	*p-val*	*Coeff.*	*p-val*	*Coeff.*	*p-val*
Milk price per litre (in cents)	340.968	0.003	39.254	0.002	16.238	0.000	37.957	0.003	-4.611	0.085	45.058	0.011	0.292	0.825
Lot size (hectares)			-0.010	0.063	-0.003	0.509	-0.009	0.117	0.014	0.003	0.018	0.017	0.010	0.000
Years living on lot	-0.392	0.331	-0.119	0.006	-0.023	0.481	-0.097	0.031	0.088	0.002	0.144	0.020	-0.003	0.829
Family size	-0.407	0.233	-0.045	0.224	0.019	0.607	-0.017	0.657	0.003	0.926	-0.015	0.779	0.009	0.574
Average age of household heads	-2.579	0.066	-0.229	0.133	0.172	0.191	-0.239	0.127	0.125	0.265	-0.330	0.124	0.099	0.075
Average age of hhd heads (Squared)	0.026	0.053	0.002	0.136	-0.002	0.222	0.002	0.162	-0.001	0.355	0.003	0.114	-0.001	0.107
Log of value of vehicles owned	0.285	0.565	0.020	0.711	0.020	0.719	-0.009	0.869	0.090	0.056	0.074	0.327	0.009	0.708
Log of payment for hired labor	-0.412	0.582	-0.088	0.278	-0.058	0.440	-0.066	0.428	0.251	0.000	0.333	0.004	0.129	0.000
Dummy for association membership	0.242	0.961	0.009	0.986	0.320	0.563	-0.007	0.991	0.729	0.125	0.848	0.266	0.341	0.147
Intercept	76.625	0.009	3.451	0.274	-3.947	0.217	4.238	0.191	-5.662	0.039	-3.123	0.484	-3.628	0.008
N	285		285		285		285		285		285		285	
Chi-Sq	2338.94		125.15		4.21 ~		177.95		11.2 ~		298.94		6.55 ~	
Prob > Chi-Sq	0.000		0.000		0.000		0.000		0.000		0.000		0.000	
Hausman test for IV														
Chi-Sq(1) at p=0.1 is 2.706	6.46		5.75		1.36		6.12		1.72		6.48		0.32	
Prob > Chi-Sq	0.595		0.675		0.995		0.633		0.988		0.594		0.998	

* A Hausman test is performed to test the efficiency of models with instrumented milk price against the non-instrumented model Based on $\chi^2_{0.1}(1) = 2.706$, the corresponding models in panels 3, 4 were estimated without using instruments for milk price.

~ Instead of Chi-Sq values, F-statistics are presented for these models

Milk price is treated as an endogenous variable with instruments in the first stage regression being – number of milk plants that farmer could sell milk to and average distance to four nearest milk plants.

Table 3.17 Seemingly Unrelated Regression of lagged price of milk on extensification and intensification (balanced panel)

	Extensification			Intensification								
	Percent of lot in pasture			Quantity of milk per pasture unit			Quantity of milk per cattle head			Stocking density		
	coeff	st error	p-val	coeff	st error	p-val	coeff	st error	p-val	coeff	st error	p-val
intercept	109.046	11.621	0.000	3.355	1.423	0.018	-27.885	49.625	0.574	4.669	1.504	0.002
New municipality	-8.848	5.716	0.028									
Lot size (hectares)				-0.005	0.003	0.084	0.108	0.095	0.257	-0.002	0.003	0.496
Years living on lot	-0.375	0.169	0.026	-0.003	0.021	0.881	0.247	0.721	0.732	-0.033	0.022	0.130
Family size	-0.278	0.210	0.186	-0.027	0.026	0.287	-1.123	0.896	0.210	0.039	0.027	0.154
Average age of hhd heads	0.141	0.090	0.120	-0.001	0.011	0.932	-0.130	0.385	0.737	-0.010	0.012	0.393
Dummy if migrated from South	4.108	2.786	0.140	0.076	0.340	0.823	-25.082	11.852	0.034	0.000	0.359	1.000
Log of value of vehicles owned	0.570	0.302	0.059	0.036	0.037	0.342	0.780	1.305	0.550	-0.015	0.040	0.713
Dummy for hired labor	1.806	2.461	0.463	0.165	0.300	0.582	13.633	10.466	0.193	0.246	0.317	0.439
Log of distance to Ouro Preto town	-10.327	1.845	0.000	0.078	0.231	0.735	12.543	8.050	0.119	0.120	0.244	0.622
Elevation	-0.034	0.026	0.185	-0.005	0.003	0.108	0.011	0.111	0.921	-0.005	0.003	0.142
Soil quality	2.743	1.037	0.008	-0.082	0.128	0.523	-0.216	4.464	0.961	-0.196	0.135	0.147
Time dummy 2000-2005	5.380	3.205	0.093	-0.926	0.391	0.018	-1.252	13.630	0.927	-0.118	0.413	0.776
Dummy for association member	-6.450	2.262	0.004	0.294	0.276	0.286	-4.334	9.622	0.652	0.225	0.292	0.441
Lagged milk price per litre (in cents)	42.413	12.816	0.001	2.766	1.565	0.077	56.317	54.565	0.302	-1.516	1.654	0.359
Lagged area in forest	-0.291	0.057	0.000	-0.017	0.007	0.023	-0.259	0.253	0.304	-0.009	0.008	0.220
Dummy if credit was invested in cattle	-0.271	5.339	0.959	1.316	0.653	0.044	30.035	22.771	0.187	0.191	0.690	0.782
N		190			190			190			190	
Adjusted R-Sq		0.384			0.146			0.121			0.125	
Chi-sq		118.48			32.77			25.82			27.19	
Pr > Chi-sq		0.000			0.005			0.039			0.027	

Robust standard errors reported

Table 3.18 Seemingly Unrelated Regression of lagged price of milk on extensification and intensification (reduced panel)

	Extensification		Intensification									
	Percent of lot in pasture		Quantity of milk per pasture unit		Quantity of milk per cattle head		Stocking density		Log of investment in cattle		Log of investment in pasture	
	coeff	p-val	coeff	p-val	coeff	p-val	coeff	p-val	coeff	p-val	coeff	p-val
intercept	139.766	0.000	3.589	0.070	-42.483	0.228	4.147	0.024	1.710	0.253	1.549	0.456
New municipality	-7.902	0.010										
Lot size (hectares)			-0.002	0.566	0.103	0.072	0.000	0.955	0.005	0.034	0.015	0.000
Years living on lot	-0.566	0.006	-0.035	0.193	-0.278	0.563	-0.052	0.039	-0.011	0.588	-0.032	0.261
Family size	-0.338	0.166	-0.029	0.373	-0.192	0.737	0.063	0.034	-0.030	0.221	-0.012	0.716
Average age of hhd heads	0.129	0.245	0.012	0.390	-0.086	0.739	0.003	0.795	-0.010	0.339	-0.024	0.110
Dummy if migrated from South	5.714	0.102	-0.129	0.779	7.550	0.355	0.409	0.337	0.323	0.351	-0.043	0.929
Log of value of vehicles owned	-0.114	0.750	0.033	0.492	-0.038	0.964	-0.055	0.213	-0.020	0.569	0.076	0.126
Dummy for hired labor	0.801	0.793	0.420	0.292	3.006	0.672	0.425	0.252	0.398	0.187	0.319	0.445
Log of distance to Ouro Preto town	-17.655	0.000	-0.001	0.998	7.348	0.207	0.063	0.836	-0.689	0.005	-0.126	0.713
Elevation	-0.026	0.374	-0.006	0.153	0.064	0.355	-0.004	0.214	0.005	0.103	-0.006	0.125
Soil quality	3.616	0.006	-0.101	0.560	-1.422	0.646	-0.352	0.029	0.097	0.462	0.100	0.585
Time dummy 2000-2005	8.192	0.031	-1.088	0.027	3.867	0.661	-0.301	0.512	6.685	0.000	2.949	0.000
Dummy for association member	-1.765	0.505	-0.007	0.983	6.707	0.275	0.103	0.747	-0.221	0.396	0.181	0.618
Lagged milk price per litre (in cents)	33.341	0.043	4.908	0.022	5.348	0.889	0.883	0.659	0.461	0.777	3.087	0.172
Lagged area in forest	-0.351	0.000	-0.027	0.015	-0.132	0.498	-0.023	0.026	0.009	0.281	0.005	0.637
Dummy if credit was invested in cattle	0.689	0.894	1.231	0.070	43.283	0.000	0.120	0.850	1.341	0.009	0.327	0.647
N	190		190		190		190		190		190	
Adjusted R-Sq	0.384		0.147		0.121		0.125		0.805		0.402	
Chi-sq	118.48		32.77		25.82		27.19		786.53		130.31	
Pr > chi-sq	0.000		0.005		0.039		0.027		0.000		0.000	

Robust standard errors reported

Table 3.19 Effect of intensification on deforestation, pasture creation and migration

	Change in area in forest		Change in area in pasture		Change in adult family members	
	coeff	p-val	coeff	p-val	coeff	p-val
intercept	31.706	0.002	-85.458	0.000	0.055	0.985
Lot size (hectares)	-0.064	0.003	0.502	0.000	-0.015	0.017
Years living on lot	0.075	0.620	-0.058	0.866	-0.123	0.008
Family size	0.247	0.203	-0.857	0.050	0.662	0.000
Average age of hhd heads	-0.075	0.356	-0.047	0.778	0.011	0.607
Dummy if migrated from South	4.832	0.043	-1.047	0.829	-0.755	0.220
Log of value of vehicles owned	-0.827	0.003	1.277	0.045	0.038	0.652
Dummy for hired labor	2.297	0.309	-10.372	0.043	0.231	0.737
Log of distance to Ouro Preto town	-2.333	0.176	14.191	0.000	0.570	0.274
Elevation	-0.054	0.017	0.042	0.368	-0.023	0.000
Soil quality	0.738	0.411	-4.646	0.012	0.005	0.983
Time dummy 2000-2005	6.012	0.342	-12.257	0.363	-2.362	0.179
Dummy if credit was invested in cattle	5.416	0.198	-14.531	0.114	-2.992	0.014
Dummy for intensification (treatment)	-15.404	0.135	50.253	0.020	8.733	0.002
N	292		292		292	
Chi-sq	106.52		253.81		245.53	
Pr > chi-sq	0.000		0.000		0.000	
Ho: Rho=0, Prob > Chi-sq	0.002		0.002		0.000	

Dependent variables reflected change and are calculated as ($y_t - y_{t-1}$). The outcomes being measures are – change in forest area, change in pasture area, change in adult family members. Robust standard errors reported.
Treatment Effects model ('treatreg' command in Stata) is used to examine the impacts of intensification on deforestation, pasture formation and migration.
Dummy for intensification = 1, if farmer reported to have made investments in improving pasture and/or cattle productivity.

More wealth but poor health?
Examining the local health impacts of iron ore mining in India

4.1 Introduction

Developing countries with large mineral deposits confront a challenge in striking the right balance between exploiting the mineral resources for broad-based, equitable development while protecting the environment. The 'Resource Curse' hypothesis proposed by Sachs and Warner (1997, 2001) is based on the consistent negative correlation between economic performance (per capita GDP growth rate) and natural resource abundance (share of exports of natural resource-based products) as observed in aggregate macro-economic data. Bulte et al. (2005) extend the literature on the resource curse by considering a broader set of welfare and development criteria; they find that natural resource abundance is negatively associated with indicators of nutrition, poverty and life expectancy. This is reflected in the public debate over mining, which is often vehemently opposed by environmental activists and public interest groups based on its poor track record on conservation of the local environment and improving welfare of local populations. On the other side of the debate, proponents of the mining industry argue that increasing employment opportunities in mines create favorable economic opportunities for the local population. In this paper, I empirically examine the consequences of mineral extraction on health outcomes of people living close to mines. By focusing on the human population that is both best positioned to take advantage of new employment opportunities and most exposed to the environmental effects of mining, I can assess the specific pathways and local

distribution of mining impacts. This level of analysis contributes to understanding the reasons for the resource curse and the possibilities for mitigating that curse through appropriate benefit-sharing mechanisms (Hancock, 2002).

The state of Orissa in India faces this challenge as it embarks upon a major reform program with the mining sector taking center stage in the growth process. Much of the proposed expansion is in remote regions with a predominantly tribal population. Previous instances of expansion of iron ore mines in the state were marred by expropriation of tribal land and large-scale displacement of villagers[25]. Besides, much of Orissa's mineral deposits are in areas close to forests that harbor rich biodiversity. Historically, mineral extraction therefore has had rather harmful impacts on forest ecosystems and the rural population in the state.

In this paper, I focus on the incidence of illness among the rural population living in close proximity to the mining area and investigate if the benefits from employment in mines outweigh the health costs. From a survey of the literature on health issues arising from mining activities, Acute Respiratory Illness (ARI) (Stephens and Ahern, 2001; Joyce, 1998) and malaria (Webster, 2001) were found to be most commonly cited besides occupational injuries. However, there exists scant evidence on

[25] New York Times, January 13 , 2006

community health impacts of iron ore mining in the public health literature, especially in the context of developing countries. Information on incidence and prevalence of illness is derived from household interviews where the respondent enumerated the number of cases of specific illnesses for individual household members and the number of workdays that each member lost due to each health problems. Using cross-sectional data, multivariate econometric models are developed to distinguish between environmental and occupational health pathways through which mines could have an impact on health outcomes of individuals. Information from household surveys is combined with spatial information on location of mines and villages to investigate associations between health outcomes, employment and proximity to mines. While no strong associations are observed for occupational health outcomes using information on employment in mines, there is consistent evidence showing that incidences of ARI increase among individuals living closer to mines, but malaria incidence in the population increase in villages further away from mines. Analyzing if employment in mines ease financial constraints for households to adopt preventive measures like improved stoves (that reduces indoor air pollution from combustion of firewood for cooking and reduce respiratory problems) and mosquito nets (that prevent mosquito bites) to reduce the incidence of ARI and malaria respectively, no strong evidence is observed.

4.2 Local health consequences of mining

Freudenberg and Wilson (2002) in a review of case studies on local socio-economic impacts of mining in United States challenge the belief that mining leads to rural development. Their results, on the contrary, point to higher observed levels of poverty and unemployment in the mining areas. Mining projects around the world have come under severe criticism under counts of land expropriation and environmental degradation that harm the livelihoods and health of local communities (Keenan et al 2002; Sosa 2000). Mining projects involve huge investments accompanied with strong political influence, and local communities could bear substantial environmental, economic, and social costs unless local governments enforce strong regulatory systems to ensure equitable sharing of benefits (Auty, 2006). An independent assessment of World Bank sponsored mining projects in India concluded that 'people living close to mines have suffered most and usually benefitted least' (Teri, 2001). However, there are few studies focusing on the health impacts of mining from a policy perspective (Hilson, 2002).

A central tenet of research on the environmental impacts of mining has been that because mines occupy a relatively small land area (when compared, for example, to other land uses like forestry or agriculture), the effects of mining on the environment will be localized (Bridge, 2004). Though dispersal of toxic wastes and other harmful

byproducts of mining by wind and water happen over wide geographical areas, the detrimental impacts are most pronounced in areas close to mines. There are direct and indirect pathways through which mines affect health outcomes of people. Employment in mines is an example of a direct pathway for impacts of mines, both in terms of the benefits from employment in mines as well as occupational health outcomes. Mines could also affect welfare though environmental health pathways that is direct as well as indirect. For example, declining ambient air quality due to spread of dust and chemicals from mining areas directly affect people living close by, irrespective of whether they work in mines or not (Sinha et al., 2007, Stephens and Ahern, 2001). On the other hand, deforestation due to mining activities indirectly affects families dependent on forest products for income generation and nutritional requirements by reducing their access to the resource base (Peters et al. 1989).

Among public health concerns for mine workers, incidence of respiratory disorders has received considerable attention in the environmental and occupational health literature (Ross and Murray, 2004; ILO, 1997)[26]. Mining in both surface and underground mines involves drilling and shearing of large quantities of minerals. The clouds of dust raised in displacing these materials can severely damage the lungs, particularly after years of exposure (Joyce, 1998). Occupational exposure to air

[26] For a review of the occupational and community health impacts of mining internationally, refer to Stephens and Ahern, 2001.

pollutants has been found to be a major cause for chronic cough and asthma, symptoms common in chronic bronchitis (Hedlund et al., 2006). However, there is a negative externality to society as individuals not employed but living close to mining areas are also exposed to the harmful effects of air pollution. Prevalence of acute and chronic respiratory health has been observed among individuals close to open cast or open pit mines (Pless Mulloli et al., 2000). In a study on opencast coal mining in the state of Orissa in India, suspended particulate matter (SPM) were found to be significantly higher than permissible limits in the mines as well as in the surrounding locations from various operations (Chaulya, 2004). In other studies on open cast coal mines, poorly maintained dirt roads and movement of heavy vehicles to transport the ore resulted in dispersion of coal dust in areas adjoining mines and cause severe air pollution (Ghosh and Majee, 2000; Singh and Sharma, 1992).

Incidence of malaria is also common in areas close to mining activities, though the pathways of health impacts are both direct and indirect. Borrow pits left after road constructions, drains and abandoned excavation areas in opencast mines often increases breeding sites for the malaria vector and directly increases malaria prevalence (Yasuoka and Levins, 2007). Deforestation caused by mining activities and subsequent change in land use and human settlement alters the local ecosystem, changes the vector ecology of mosquitos and indirectly affects malaria incidence (Patz et al., 2004, Takken at al. 2003). Among all states in India, the incidence of malaria is the highest in the state of

Orissa (Kumar et al., 2007). A cross-sectional study conducted in 1989 in settlements in the iron ore mining region in Orissa found high densities of the malaria vectors. Children were found to be most vulnerable to malaria attacks and the poor casual laborers in the mines were found to be worst affected in economic terms (Yadav et al., 1991).

In a study conducted by the World Resources Institute (2004), 75% of active mines and exploration areas were found to overlap with areas of forests with high conservation value and areas of watershed stress at the global scale. This substantiates the common concern about deforestation both due directly to mining activities and indirectly due to increased access, economic activities, and immigration. Sediment flows from iron ore mines are also found to affect downstream water quality as well as drinking water and irrigation facilities (Krishnaswamy et al., 2006).

4.3 Prevention options to mitigate incidence of ARI and malaria

In order to identify the impact of mining on incidence of ARI and malaria on people living close to mines, the preventive measures undertaken by the households need to be accounted for. Failing to do so could result in imprecise estimation of the impacts of mining activities on health outcomes. If mine employees allocate part of the income they earn from mines to prevention activities that reduce the incidence of these

illnesses, then ignoring such averting behavior will under-estimate the health impact of mines. We consider interventions that are commonly promoted by development and public health agencies in developing regions – adoption of improved stoves and construction of well-ventilated kitchens that reduce indoor air pollution from combustion of firewood, and use of mosquito nets while sleeping. Individual members can suffer from ARI related problems either due to air-borne pollution from mines, or from the domestic combustion of firewood for cooking. The respondents in the survey reported days ill due to ARI–related problems, which cannot be specifically attributed to either of the two sources. In this paper, I control for domestic cooking methods to investigate direct impacts of mining on ARI related diseases, and whether income from mines facilitate adoption of the preventive measures like improved stoves and ventilated kitchens. Use of mosquito nets help reduce the probability of being bitten the malaria vectors. Abandoned areas in and around mines is one of the possible breeding grounds for the malaria vector. Again, I control for agricultural area close to the village (with stagnant water before cultivation) to check for impacts of proximity to mines on malaria incidence.

Over half of the world's population still relies on biomass fuels and coal to meet domestic energy needs (Matthews, 2000). Transition to cleaner fuels among the poor has slowed dramatically and there is evidence that reliance on biomass is increasing in some parts of the world (WHO, 2006). Typically burnt in open fires or poorly

functioning stoves, the use of biomass fuels leads to very high levels of indoor air pollution. The products of incomplete combustion from small-scale biomass combustion contain a number of health-damaging pollutants, including small particles, carbon monoxide, poly-aromatic hydrocarbons and a range of toxic volatile organic compounds (Bruce et al., 2000). Current best estimates, based on published epidemiological studies, are that biomass fuels in households are responsible annually for approximately 0.7 to 2.1 million premature deaths in low income countries from a combination of lower-respiratory infections, chronic obstructive pulmonary disease and lung cancer (WHO)[27]. About two-thirds occur in children under the age of five and most of the rest occur in women (Smith et al., 2004). 70% of the population living in rural India traditionally cooks using unvented stoves with women and children experiencing the highest exposures to harmful levels of particulates, carbon monoxide, nitrogen oxides and other products of inefficient biomass combustion. Traditional fuels (firewood, crop residue, dry leaves, dung, etc.) constitute about 90% of the total energy used in rural households (PCIA India 2004 report[28]) and 75% of it came from fuelwood (NCAER, 1993). The National Program on Improved Chulhas (NPIC) was launched in 1983 and by 2000 had disseminated about 32 million improved stoves nationwide. Primary objectives of the Program included reduction in demand and conservation of fuelwood, removal of smoke from kitchens, reduce drudgery for women and children,

[27] http://www.who.int/mediacentre/factsheets/fs292/en/index.html
[28] http://www.pciaonline.org/atf/cf/%7B3F7B64BF-ADAD-479B-B81F-AB7C6A5426B8%7D/India_Household_Energy_and_Health_Overview.pdf

and create employment in the rural areas (Jalajakshi 2005). In a recent study of indoor air pollution in Bangladesh, construction of the kitchen with proper ventilation was found to yield better indoor air quality (Dasgupta et al., 2007).

As mentioned before, the state of Orissa has the largest number of reported malaria cases in India. Partnerships between donor agencies, local NGO and communities have been established to raise the awareness and disseminate of insecticide-treated bed nets (Barat, 2006). As compared to other methods of malaria vector control like indoor residual spraying of DDT, use of bed nets is technologically simpler and more cost-effective (Misra, 1999). In a randomized trial of insecticide-treated bed nets in Sundargarh district of Orissa (adjacent to location of the present study), relative risk of malaria and parasite rates declined significantly in villages with treated nets (Sharma et al., 2006). The study concluded that considering the development of resistance among malaria vectors to DDT, bed nets treated with Deltamethrin could be an effective alternative strategy to control malaria. In another study in India, the use of treated bed nets had a marked reduction on malaria transmission, but little effect on vector density (Misra, 1999). This suggests that while there were private benefits from use of mosquito nets, the use of nets did not help in reducing the societal danger of malaria attacks on those not using nets or taking other preventive measures.

In spite of the benefits of these preventive measures in reducing the incidence of ARI and malaria, the rate of adoption has been consistently below expectations of the agencies and NGOs promoting them. Dasgupta et al. (2007) and Wallmo (1998) believe that a reason behind the low rates of adoption of cleaner, fuel-efficient stoves is that rural families find it difficult to make the investments required for installation and maintenance of these stoves. In two studies examining the factors underlying household use of bed nets in Africa, Meltzer (2003) and Nuwaha (2001) found that bed nets were only used by richer households in the community. Both studies emphasize the necessity of subsidizing the bed nets to make it affordable to the majority of families. These empirical findings suggest that increased cash income – for example, from employment in mines – could increase adoption rates. If employment in mines did help households overcome cash constraints on adoption of improved stoves, kitchen ventilation, and bednets, this could have important welfare impacts on families – not only reducing the burden of ARI and malaria, but also saving money other wise spent on treatment, reducing the number of wage-earning days lost due to illness, allowing children to attend school and women to increase time devoted to child care and housework.

4.4 Study area

The state of Orissa lies along the eastern coast of India (Figure 1). Besides large reserves of chromium, bauxite and manganese, Orissa has the largest reserve of

superior quality hematite iron ore in the country (Sengupta, 2005). The recorded forest area in Orissa in 2003 was 4.84 million hectares, which constituted 31% of the geographic area and ranked fourth among Indian states in terms of total forest cover[29]. However, in comparison with 1999, forest cover had decreased by almost a million hectares[30]. The mining belt along the Northern border of the state is one of the most important reserves in the country[31] and coincides with most of the remnant forest. Within Orissa, Keonjhar district was selected for this study because of the concentration of iron ore mines in the Joda-Badabil mining belt in Joda block (Figure 2)[32]. 31% of the number of people working in mines in Orissa is concentrated in the district of Keonjhar, indicating the importance of the mining industry in the region. Mining for iron ore in the district began in the 1950s under the purview of the state government. However, following the privatization of the mining sector, much of the potential expansion will open up new mining areas in this region. The district had a relatively high percentage (42.7%) of forest cover in 1999 (Forest Survey of India,

[29] 'State of Forest Report' published b y the Forest Survey of India in 2003; http://www.fsiorg.net/fsi2003/states/index.asp?state_code=21&state_name=Orissa

[30] 'State of Forest Report' published by the Forest Survey of India in 1999; http://www.envfor.nic.in/fsi/sfr99/sfr.html

[31] 97% of Bauxite, 95% of Nickel, 76% of Graphite, 50% of Bauxite and 34% of India's iron ore deposits are in the region (Source: Status paper on mining leases in India. Vasundhara, India). Downloaded on March 31, 2008 from : http://www.freewebs.com/epgorissa/M%20I%20Update/Status%20Paper%20on%20Mining%20Leases.pdf

[32] Keonjhar district has 20% of all the mining leases granted by the State government of Orissa. The district has more than 12076 hectares of iron ore mining areas under 46 mining leases, making it the most important iron ore mining center in Eastern India (Source: Status paper on mining leases in India. Vasundhara, India).

1999). But, in the two blocks selected for this study, analysis of the classified land cover data reveals that 13.4 square kilometers of vegetative cover were replaced by expanding mining areas between 1989 and 2004.

In the absence of field monitoring and measurement data on ambient air quality, study villages were selected based on proximity to mines. The rationale behind the first stage of the sample selection process is simply that villagers living closer to mines are more exposed to impacts of mines than those further away. On the basis of government census data on mine employment and location of mines, two blocks were selected in Keonjhar district – Joda and Keonjhar Sadar. Joda block has a large concentration of iron ore mines, as confirmed by the fact that 68% of mine workers in Keonjhar district live in Joda block. On the contrary, Keonjhar Sadar block has a much lower concentration of mines and only 1% of people employed in the mining industry live in this block. In the second sampling stage in each of these blocks, 10 villages were selected at random. Finally, in each of these villages, 30 households were selected from each village to be interviewed. For convenience, villagers in the Joda block henceforth will be referred to living in the ‘high exposure’ zone while Keonjhar Sadar will be referred to as the ‘low exposure’ zone.

4.5 Description of the data

The dataset consists of two elements – (1) a household survey administered to 600 households with specific modules consisting questions on incidence of ARI and malaria among family members; (2) forest cover maps derived from Landsat satellite imagery for 1989 and 2004, and GIS information on locations of mines and villages. For indicators of health outcomes, we use reported information on types and days of illness specifically pertaining to incidence and workdays lost due to of ARI and malaria[33]. Information on the number of iron ore mines was collected from the database maintained by the directorate of mines. Information from survey topo-sheets and remotely sensed data was combined with the mining database to identify the location and area of iron ore mines in the study area. These mines are under state as well as private ownership, operating under various levels of modernization and mechanization. Observations from field visits to a sample of mines in the study area revealed apparent variations in abidance to environmental regulations prescribed by the Department of Mines, which has repercussions on occupational and environmental health issues. For exposure to mines, GIS information on location of mines and villages are used to

[33] Unless mentioned, incidence and workdays lost due to ARI is based on the reported information on whether an individual had suffered from ARI in the year prior to the survey in 2005. For malaria, this is based on information from 2001 to 2005.

construct a proxy measure based on Euclidean distance to the nearest iron ore mine[34]. As a result of the study design, villages in the high exposure and low exposure zones are within a range of 0.2 to 4 km and 6 to 21 km from iron ore mines respectively. Note that all the villages fall within the "Peripheral Development Zone" of 50 km[35] - a specification followed in mining and development projects supported by the World Bank to address issues related to local impacts of mines. The descriptive statistics of the variables used in the analysis is reported in Table 1.

A total of 600 households (300 in each block) were interviewed and information was collected for 2949 individuals. Out of 600 households, 175 out of 300 households interviewed in the high exposure zone reported at least one family member to be working in the mines, while the corresponding number in the low exposure villages was 45 out of 300 households[36]. 283 individuals from 220 families reported to be working

[34] Alternative definitions of exposure based on 'number of mines in a 2km buffer around each village' were used in the analyses which provided similar results. I stick to using the Euclidean distance based measure for exposure to mines in this paper. Besides the mining areas, there are unregistered, small-scale stone-crushing units in the study area and the dust from these units cause significant air pollution. However, these units do not operate in the same spot for a long period of time to avoid impoundment, and their effect on ARI specifically is difficult to assess. Based on data and field observations, proximity of villages to these stone-crusher units is highly correlated to distance to iron ore mines.

[35] World Bank report on the study 'Towards Sustainable Mineral Intensive Growth in Orissa, India' is available at:
http://www_wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2007/12/21/000020953_20071221103718/Rendered/PDF/398780IN.pdf

[36] The household questionnaire had modules to record the occupation details of every household member. Employment of a family members in mines was determined for the cases where a member was reported to be working as a 'non-farm worker as factory worker'. Employment in the stone quarries was determined based on member occupation being 'non-farm work as construction labor'.

in mines[37]. Table 2 shows the distribution of health outcome variables in the full household sample and the two blocks separately. The average number of reported cases of ARI in the family was significantly higher in the high exposure zones as compared to the low exposure zones (1.2 compared to 0.8). However, the average number of reported cases of malaria in the family was higher in the low exposure zone (1.8 compared to 1.5). While the average number of workdays lost per family due to ARI was not significantly different across exposure zones, families in the high exposure zones reported more number of workdays lost due to malaria (19.5 compared to 12.5). A reason for this trend could be the fact that incidences of malaria are lower in the high exposure zone, but the severity of malaria is worse in the high exposure zone. Correlations with distance to iron ore mines show that workdays lost increases among villages with greater proximity to mines. Note that the mean and variance of count of ARI and malaria variables are similar and thus we model these two variables as a Poisson process in our econometric estimation.

Table 3 ranks the villages in ascending order of distance to iron ore mines based on the calculated Euclidean distance. The '+' ('-') sign indicates if the village average was greater (lower) than the sample average. The incidences of ARI and malaria reveal a very different spatial pattern – ARI seems to be more prevalent in villages in the high

[37] Another 103 individuals from 65 families reported to be working in stone quarries. As mentioned before, these stone quarries operate illegally and employment in these units is temporary in nature. I ignore quarry employment in the subsequent analyses.

exposure zone, while malaria is a more common occurrence in the low exposure zone. However, as observed in table 1, more workdays are lost in the high exposure zone due to malaria as compared to the low exposure zone. No specific patterns are observed for workdays lost due to ARI.

Table 4 presents the results on health status breaking down the population into 3 sub-groups – (i) individuals with no family members working in mines, (ii) individuals with some family member working in mines, (iii) individuals working in mines themselves. Parsing the sample into these subgroups helps to better distinguish the occupational health impact on individuals from mine employment. While individuals in group (i) should have no occupational health effect, those in group (ii) only have an indirect effect as members working in mines could transmit ARI or malaria contracted while working in mines among other family members. Group (iii) represents the sub-sample most likely to suffer a direct occupational health effect from working in mines. There is no significant difference in ARI related health indicators across these three groups, except for expenditure where individuals not working in mines report having spent more. For malaria, those who work in mines suffer more in terms of workdays lost as well as significantly spend more on treatment.

4.6 Conceptual framework

On a national scale, one of the debates surrounding the development of the mining sector is to weigh the prospective gains for economic growth utilizing the natural capital of mineral assets with the looming concern for mining being a 'footprint industry' that leaves in its trail detrimental economic, social and environmental impacts (Weber-Fahr, 2002). As mentioned in the introduction, analyses of various indicators of economic performance and development metrics have been found to fare poorly vis-à-vis natural resource abundance (Bulte et al., 2005, Sachs and Warner, 2001). However, countries that have achieved parallel improvements in human capital have been found to more than offset the expected negative effect of natural resource abundance on economic growth (Bravo-Ortega and De Gregorio, 2005). On the other hand, the potential negative impacts of mining are localized in nature and often tend to be under-estimated in evaluation of the sustainability of extractive industries at the national scale. The paper focuses specifically on examining the local public health impacts to provide insights on the sustainability of the mines.

From a public policy perspective, the 'weak sustainability' criteria proposed by Hartwick (1977) provides a conceptual foundation to explore this issue. Based on the premise that different forms of capital are fungible, the mining enterprise could comply with the 'weak sustainability' criteria as long as improvements in quality of life and

public infrastructure for the population affected by mines offset the loss from the depletion of non-renewable mineral stock and associated loss of agricultural, forest lands due to excavation. As a thought exercise, Hamilton et al. (2005) found that resource-rich countries that currently rank low on wealth indicators would have ranked much higher on the scale had they followed the Hartwick rule. In the Indian context where mines are government or privately owned, the rent from mineral extraction seldom gets reinvested locally in developing public infrastructure and improving living conditions of villagers directly affected by the mining activity (Sinha et al. 2007). The conceptual framework takes into account the possible negative externalities that were found in general from the literature review and specifically in the Indian context (World Bank Report, 2007).

Figure 5 presents a conceptual framework to analyze the possible impact of mining on public health. Mining operations can generate both direct and indirect health impacts for the proximate population, and some of these pathways are further categorized as environmental and occupational. There are direct financial benefits from employment in a mine if the opportunity cost of working in the mines is lower than the mining wage. The increase in income may reduce the cash constraints of families to invest more in illness prevention measures that improve overall health status. Proximity to mines has direct and indirect negative health effects as well. Mines that fail to meet prescribed environmental standards are more likely to generate direct negative

externalities for those who are employed in mines (occupational health), as well as through negative externalities for those who do not work in mines but live close to it (environmental health). In the context of the paper, the dust and other harmful suspended particulate matter could increase ARI-related health problems, or abandoned areas with stagnant water become breeding grounds for mosquitos that cause malaria. Large areas had to be deforested to establish the open cast mines in the region. This imposed a financial and nutritional burden on the villagers in the study area who relied on sale and consumption of forest resources for their livelihood.

This framework provides a more nuanced description of the complex set of relationships that connect mining with public health concerns. It helps separate causal pathways, provides a set of testable hypotheses and the empirical analyses required to verify those (Ethridge, 2004). The specific hypotheses that I focus on in the econometric section are: (a) proximity to mines increase incidence of ARI and Malaria; (b) income from mines reduces financial constraints for farmers and enables them to invest in preventive activities that reduces the burden of illness.

4.7 Econometric models for health outcomes

In the first step of the econometric model, the individual-level dataset is used to model two separate outcomes related to ARI and malaria – (1) whether an individual

member reported an incidence of ARI and malaria (Probit); (2) the reported number of workdays lost by individual members due to ARI and malaria using 3SLS and count models. The empirical model for both cases is outlined as follows.

Let (y) be the outcome of interest – either incidence or workdays lost due to ARI and malaria. These health outcomes are a function of a vector of individual-specific characteristics (I), household-specific characteristics (H), location of the household (L), environmental health variables (EH), occupational health variables (OH) and preventive behavior (P).

$$y = F(I, H, L, EH, OH, P) \quad (1)$$

where $F(.)$ depends on whether incidence of ARI/Malaria (a binary variable) or workdays lost due to ARI/Malaria (count variable) is being modeled.

The variables used in each group are:

Individual-specific (I): Age, sex, education, number of hours devoted to wage employment on an average day by individual member.

Household-specific (H): Caste, amount of fuelwood used for domestic consumption, amount of irrigated land in village.

Location of household (L): distance to paved roads, distance to primary health center.

Environmental health (EH): distance to nearest iron ore mine using GIS information.

Occupational health (OH): dummy if individual is employed in mines, number of days reported to be working in mines.

Preventive behavior (P): Use of improves stoves for cooking, dummy if kitchen is partitioned from the house or not, dummy if bed nets are used for sleeping.

4.7.1. Probit model for incidence of ARI and malaria:

A binary variable was constructed based on the information of which individual family member had occurrence of ARI and malaria. A Probit of the following form is estimated:

$\Pr(y = 1 \mid X) = G(\beta_0 + \beta X)$, where (X) is a vector of explanatory variables specified in (1) and $G(.)$ is the standard normal cumulative density function. Individuals within the family have the choice of working in mines, which makes mine employment endogenous to the model. I use proximity to mines, average number of hours worked in wage employment, dummy if land owned and years of education as instruments for mine employment and estimate the Probit as a 2SLS model.

Results from the Probit are shown in Table 5. The environmental health variable, measured by Euclidean distance to the closest iron ore mine is significant

across the two models, but with opposite signs. While as distance to mines increase by 1 km, the probability of a family member being affected by ARI problems decrease by 2.3%, while the probability of malaria increase by 1.9%. This result mirrors the previous observation that villagers closer to mines in the high exposure zone reported a higher incidence of ARI, while those further from mines in the low exposure zone reported a higher occurrence of malaria. Employment in mines, after being instrumented, is negatively affected with the incidence of ARI – an additional day of employment in mines reduces the probability of ARI by 0.1%. Employment in mines increases the probability of malaria, though the result is not significant. None of the demographic variables, except whether the family belongs to a scheduled tribe, is significant. Generally, people belonging to the scheduled tribes are historically marginalized, and 70% of the mine workers in our sample belong to scheduled tribes. This result raises the doubt of under-reporting of health status information by this group. Location-specific variables like distance to paved roads and primary health center had little explanatory power. I use the log of amount of fuelwood consumed by the household to control for the fact that combustion of firewood for domestic cooking and heating could also lead to higher incidence of ARI. If this factor is ignored, then the impact of mines on ARI incidence could be over-estimated. Increase in firewood use has the expected effect of increasing ARI, but the effect is not significant. In the case of malaria, I control for the amount of irrigated land and change in forest cover around the village – factors that could affect the incidence of malaria. The significantly negative

effect of irrigated land on incidence of malaria is surprising, as Patz (2004) argues that irrigated agricultural fields often provide breeding grounds for mosquitos. Given the clustered nature of these villages, agricultural land is arranged in concentric circles around the villages. Irrigation in agricultural fields often results in stagnant pools of water in the land surrounding the villages and was suspected to provide breeding areas for mosquitos. However, given the highly seasonal nature of rain-fed irrigation and the economic importance of agricultural land for households, the irrigation variable might be working as a proxy for welfare in the low exposure villages. Villages with a greater decrease in forest cover in a 2km buffer around the village reported higher incidence of malaria, but the effect was not significant. The prevention variables all have expected signs and are highly significant – incidence of ARI reduces by 75% and 23% among individuals who have improved stoves and partitioned kitchens in their house respectively. Incidence of malaria reduces among individuals by almost 12% if they use insecticide-treated bed nets in the house.

4.7.2. 3SLS models for workdays lost due to ARI and malaria:

In the sample, workdays lost due to ARI and malaria has a range of 0 to 90 days each. In this model, workday lost is treated as a continuous variable and a 3SLS model is developed. Employment in mine is assumed to be endogenous and is estimated simultaneously with workdays lost due to ARI and malaria. The error term in both

equations is assumed to be correlated due to unobserved heterogeneity and 3SLS estimation method is employed.

Table 6 shows the results from these two models. The environmental health variable remains significant and negative for both the ARI and malaria models. Recall that Tables 1 and 2 indicated that though the incidence of malaria was high in the low exposure zones, the number of workdays lost due to malaria was higher in the high exposure zone leading to the conjecture that the severity of malaria is worse in villages closer to the mines. These general observations substantiate the negative coefficient with distance to iron ore mines. Living 1km closer to the iron ore mines increases the workdays lost due to ARI and malaria by 0.02 and 0.08 days. The instrumented occupation health variable is not significant across either of the models. Older individuals suffer more days of lost work due to ARI. Individuals belonging to the scheduled tribes and scheduled castes report less workdays lost due to both ARI and malaria. Compared to models in table 3, increase in forest cover in a 2km buffer around villages (comparing 1989 and 2004 classified land cover data) is found to increase the workdays lost due to malaria. Loss in forest cover in a 2km buffer around sample villages was higher in the low exposure zones than in the high exposure zones (2.3 sq. km compared to 0.31 sq km), and the spatial distribution of greater malaria incidence in the low exposure zones supports the deforestation-malaria hypothesis. However, malaria incidence or workdays lost cannot be attributed to deforestation due to mining activities. Location-specific variables still remain largely insignificant, except that

workdays lost due to ARI are higher for individuals living further away from the primary health center. The prevention variables continue to have the expected signs, but only kitchen construction and use of bed nets are significant.

4.7.3. Count data models for workdays lost due to ARI and Malaria:

While the range for reported workdays lost by individuals due to ARI and Malaria ranged between 0 and 90 days, more than 99% of the sample lost between 0 and 20 days for each illness[38]. Unlike treating workdays lost as a continuous variable as in the 3SLS models estimated in (ii), an event count model is estimated.

Assuming that the number of workdays lost (d_i) by an individual follows a Poisson distribution with observed frequency (y_i), given the vector of explanatory variables (X_i), the probability of observing the count (y_i) is defined by

$$\Pr(d_i = y_i) = e^{-\mu_i}\mu_i^{y_i} \Big/ y_i!, \text{ where } y_i = 1,2.....20 \qquad (2)$$

with the mean parameter

$\mu_i = E(y_i \mid X_i) = Var(y_i \mid X_i) = \exp(X_i'\beta)$, where (β) is the parameter vector

[38] For ARI (malaria), out of 631 (1009) individuals reporting workdays lost to illness, only 14 (5) reported to have lost more than 20 days due to ARI. These models are thus run with the restricted sample where reported workdays lost due to ARI and malaria was less than or equal to 20 days.

The equality of the conditional mean and variance in the Poisson model (PRM) imply a particular form of heteroskedasticity in the model, known as equidispersion (Cameron and Trivedi, 1998). In real-world data, counts are usually overdispersed, implying that conditional variance is greater than the conditional mean (Long and Freese, 2006). This problem is dealt with using a Negative Binomial regression model (NBRM) (Cameron and Trivedi, 1998). The mean structure remains the same between the PRM and NBRM models, but the variance function[39] is modified such that

$$Var\left(y_i \mid X_i\right) = \mu_i + \alpha.\mu_i^2$$

There is equidispersion as long as $\alpha = 0$ and the NBRM, PRM models are identical, while $\alpha > 0$ takes account of the overdispersion in the data. The density functions for $d_i > 0$ and $d_i = 0$ can be written as

$$\Pr_{NB}\left(d_i = y_i\right) = \left[\frac{\Gamma\left(y_i + \alpha^{-1}\right)}{y_i!\Gamma\left(\alpha^{-1}\right)}\right].\left[\frac{\alpha^{-1}}{\alpha^{-1}+\mu}\right]^{\alpha^{-1}}.\left[\frac{\mu}{\alpha^{-1}+\mu}\right]^{y_i}$$, where Γ is the Gamma function

$$\Pr_{NB}\left(d_i = 0\right) = \left[\frac{\alpha^{-1}}{\alpha^{-1}+\mu}\right]^{\alpha^{-1}} \quad (3)$$

[39] This is the function used in (Cameron and Trivedi, 1986) and is referred to as the NB2 because of the squared term $\left(\mu^2\right)$, though other variance functions can also be used.

A frequent occurrence of overdispersion in count data results from an excess of zero observed in the data than is consistent with the Poisson model. The PRM and NBRM is based on the assumption that every individual has a positive probability for the count outcome, to lose workdays due to ARI and malaria. However, there could be a possible set of factors that preclude individuals from being affected by such illness. As a result, the process generating zero outcomes in the data will be different from those generating the observed positive outcomes. The zero-inflated models (Lambert, 1992) assume two different processes generating the data – one explaining the zeros, and the other for the positive outcomes. Given the probability (φ) of not losing any workdays due to ARI and malaria,

$$\Pr(d_i = 0) = \varphi_i + (1-\varphi_i).e^{-\mu_i} \quad (4)$$

$$\Pr(d_i = y_i) = (1-\varphi_i).\left[\frac{e^{-\mu_i}.\mu_i^{y_i}}{y_i!}\right], \text{ where } y_i = 1,2.....20 \quad (5)$$

The probability of zero and positive workdays lost is a combination of the first stage equation in (4), which follows a logistic distribution given a vector of explanatory variables X_i and the Poisson distribution from (2). This is the Zero-inflated Poisson model (ZIP). Instead of using (2), using (3) in the second stage produces the Zero-inflated Negative Binomial model (ZINB). The vector of explanatory variables used in

(4) and (5) may not be the same, depending on specifications of the processes that presumably drive the zero and positive outcomes.

In the next step, results from a series of exploratory analyses are presented to guide the search for the best model that explains workdays lost due to ARI and malaria. Figure 6 and 7[40] graphically show the predictions of the 4 different models described above with the observed distribution of workdays lost due to ARI and malaria respectively in the data. There are two panels for each illness, and the first panel in each figure highlights the fact that PRM significantly under-predicts 0 and over-predicts counts 1, 2, and 3. The NBRM, ZIP and ZINB models appears to predict the lower counts including 0 significantly better. The second panel magnifies the image to indicate how the models perform in predicting higher counts, those which occur with lower probabilities. While the ZIP consistently over-predict higher counts, the PRM and NBRM tends to under-predict higher counts. The observed data appears to hover around the predictions from the Zero-inflated Negative Binomial model, though visual evidence is inconclusive in the identification of the best model.

Table 7 and 8 contains summary of results and model fit statistics from estimation of the PRM, NBRM, ZIP and ZINB models. Validating the results from the

[40] In these graphics, the count is restricted to 9 as it is increasingly difficult to differentiate the graphs for higher counts because of little variation in scale on the y-axis.

graphs in Figures 6 and 7, the test for overdispersion in the PRM model is highly significant across comparisons with the other three models. Having confirmed that either the NBRM or the Zero-inflated models fit the data better, the significance of the Vuong statistic indicates that the Zero-inflated models should be preferred. The model fit statistics indicated by the Log likelihood, Bayesian Information Criterion and Akaike Information Criterion show that the ZINB model is preferred over the ZIP. As a result, the detailed estimation results from the ZINB model are presented in Table 9. Comparing results in Table 7 with the 3SLS results in Table 6, the Occupational Health variable (days worked in mines) is insignificant and becomes negative in the zero-inflated models. The Environmental Health variable (distance to nearest iron ore mine) is consistently negative but insignificant[41]. The prevention variables all have expected signs, but only use of improved stoves remains significant in explaining reduction in workdays lost due to ARI. Amount of firewood consumed is surprisingly significantly negative across all models, another result that deviates from the 3SLS model. Male family members reported to have lost more workdays lost due to ARI, which is likely as most of the wage labor are done by male members and are more likely to report loss of working days compared to female members mostly engaged in household chores. In the model for malaria in Table 8, the Occupational Health variable remains positive but insignificant across all models. The Environmental Health variable is significant and

[41] When the logarithm of distance to nearest to iron ore mines is used instead, the coefficient is just significant at the 15% level.

negative, indicating that while incidence of malaria is lower in villages closer to mines, those living closer report to have suffered more from workdays lost due to malaria. The use of mosquito nets reduce workdays lost due to malaria, though the significance of the variable wanes in the ZINB model compared to PRM and NBRM. Workdays lost increases with more land in irrigation and greater loss of forest cover around the village, as was surmised from the literature review.

Based on the best fit of the ZINB model, the results from estimating workdays lost due to ARI and Malaria are presented in Table 9. As indicated in equations (4) and (5), the results under the 'inflation equation' correspond to the model in equation (4) that is specifically for the zero responses in the data. The ZINB model assumes that the underlying process generating the large number of zeros in the data is different from the process that generates the count variable of workdays lost. I hypothesize that respondents are more likely to correctly recall number of workdays lost in situations where they are engaged in off-farm wage employment. As a result, individuals in families below the poverty line are more likely to under-report workdays lost due to illness. Respondents with larger families could also under-report, either because of recall errors for all the members, as well as interview fatigue. The coefficients for both these 'inflation' variables are positive and significant. The results pertaining to equation (5) corresponds to the negative binomial model. An individual living 1 km closer to an iron ore mine will increase the number of workdays lost to ARI by 0.5%. Being a male

reduces workdays lost by 13%, raising the concern that women members in the household are more susceptible to ARI related problems, though the use of firewood for cooking is a critical factor for that. There is no perceptible difference in workdays lost for individuals with mine employment. Families with improved stoves and partitioned kitchen reduce workdays lost to ARI by 11% and 2% respectively. For the malaria model, an individual living 1 km closer to an iron ore mine will increase the number of workdays lost to malaria by 7%. A 1% increase in area under irrigation around the village increases workdays lost to malaria by 3%, while 1 sq. km. of deforestation around the village increases workdays lost by 1.5%. A family with an additional mosquito net reduces workdays lost to malaria for individual members by 10.5%.

As a summary of the results from these sets of model, there is little evidence of occupational health for either ARI or malaria. The environmental health effect, using the proxy of proximity to mines, is more pronounced, as evident for ARI in the 3SLS model and on malaria in the ZINB model. The hypothesis that higher deforestation leads to higher prevalence of malaria was only supported in the ZINB model, though this deforestation could not be attributed to mining activities alone as more deforestation took place in the low exposure zone. Another robust result from the models reflects the importance of prevention activities on individual health outcomes. Preventive measures like adoption of improved stoves and construction of partitioned kitchen inside homes reduced the incidence and workdays lost due to ARI. Use of

insecticide-treated bed nets also reduced the incidence and workdays lost due to malaria. From a public health policy perspective, it is important to identify factors that influence the adoption of these prevention measures.

4.8 Factors affecting use of prevention measures

Families make decisions regarding the adoption of the three preventive measures based on their subjective utility post-adoption. It is important to point out that these prevention measures help reduce the burden of ARI and malaria related health problems among family members, irrespective of whether these problems were induced by mining activities or not. The typical approach to model adoption behavior of individuals is to discrete choice model. Among the factors that could affect adoption, most interest lies in the fact that whether cash income from employment in mines eases the cash constraint facing poor, rural households thus facilitating investment in preventive measures. There are also opportunities for individuals to observe the changes in outcomes among neighbors in the village who use these prevention methods.

This kind of exchange of information among residents in the village often influences adoption decisions of individuals (Dickinson and Pattanayak, 2008). In the model, evidence for such kind of social interaction effect in adoption of these preventive measures is also tested in the model. The household's latent utility from

adoption of preventive measures can be modeled as set of household specific and location-specific characteristics, such that

$$B_i^* = b(X_i, B_{-1}) + e_i$$

where, B_i is the individual adoption decision, B_{-i} denotes the adoption decision of other members in the village and X_i is a set of household and location-specific characteristics.

This model is estimated using a probit regression such that the likelihood function is of the form:

$\Pr(B_i = 1 \mid X_i, B_{-i}) = 1 - F(-\beta X - \theta B_{-i})$, where, $F(.)$ is the standard normal cumulative density function.

The results of the estimation are presented in Table 10. Three sets of models are presented relevant to each of the preventive behaviors. Given the economic importance of agriculture in the region, dummy for land ownership represents wealth status of a household. Based on the dummy for land ownership, households owning land had a 14% (24%) higher probability of using bed nets and improved stoves. As was the case with employment in mines in previous models, days worked by an individual in mines is treated as endogenous and instrumented using average time devoted by family members to wage employment and Distance to iron ore mines. The probability of

adoption of improved stoves is found to significantly increase with employment in mines. As mentioned before, dissemination of improved stoves in rural areas in Orissa are being promoted through micro-credit organizations (Duflo, 2007). These organizations are yet to be operational on a large scale in the region and the lack of significance of participation in micro-credit organizations in the promotion of improved stoves or bed nets indicates this. As a matter of fact, 72 of the households that reported having improved stoves in the region were not members of any micro-credit groups in their village. Among the factors used to examine the impact of social influence on household adoption decision, two variables were considered – count of adoption by other members in the village and number of social organizations that members of the individual households participate in. Only in case of adoption of bed nets was the village count of adoption significant, indicating that individual adoption of bed net increases by 3.6% when one more family in the village adopts. Participation in village level organizations increases the scope of interaction and sharing experiences with other villagers. Such social organizations and NGOs have been found to be important nodes of information regarding adoption of new technology (Bandiera and Rasul, 2006). This variable was significant only in the case of adoption of bed nets.

The cross-sectional analysis precludes inferences of any causal nature such as mine employment causes greater use of preventive measures. However, the results

point to the possible effect where increase in cash income from mine employment allows cash-constrained rural families to better invest in prevention of ARI and malaria.

4.9 Conclusion

This study is one of the first attempts towards comprehensive analyses of local health impacts of mining in India. There is a raging public policy debate surrounding the proposed expansion and privatization of the mining industry in Orissa, but any systematic analyses of the distribution of costs and benefits among the various stakeholders involved that can inform the policy debate have been conspicuously absent. By examining the local health impact of iron ore mining, the paper focuses on the repercussions of mining on a stakeholder, the local population, which is often missing from the debate.

Methodologically, the paper points to the data challenges inherent in comprehensive policy analysis of this nature. The results were extremely significant to variable construction and model assumptions. While multi-disciplinary expertise is a necessity in correctly identifying, formulating and linking the various dimensions of the debate, it simultaneously imposes great demands on data quality and diversity that can provide the empirical rigor to such an approach. The requirements of longitudinal data

are also crucial in such applied policy analysis, the absence of which prevents the kind of causal inferences that can inform public policy.

From a public policy perspective, the analysis does not provide unambiguous answers to the impact of mining on the local population. Malaria was found to be more common in villages further from mines, but the severity of malaria as measured with workdays lost was greater in villages closer to mines. The results of ARI were less ambiguous as people closer to mines reported worse outcomes as compared to those living further. While negative health outcomes were associated to proximity to the mining areas, there was also significant evidence supporting correlations between mine employment and better adoption of prevention measures designed to reduce the burden of ARI and malaria. This finding paves way for more directed future research looking at the relative contributions of increased cash income in alleviating illnesses vis-à-vis correctly identifying how exposure to mines is responsible to specific health problems.

4.10 Appendix

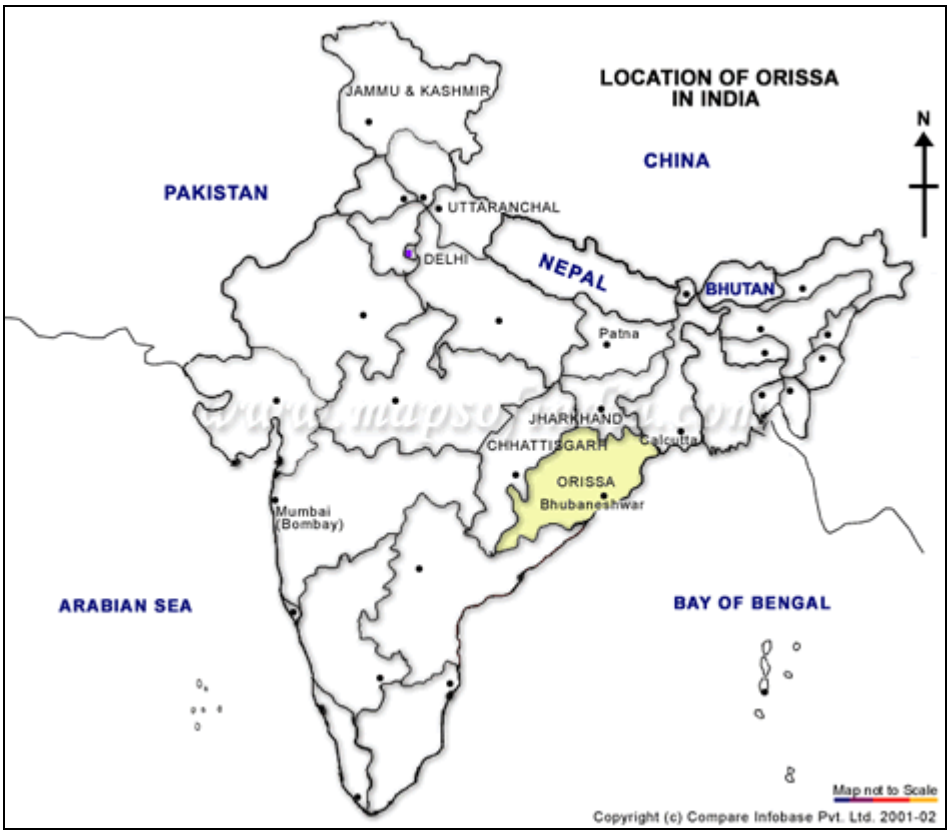


Figure 4.2 Location of the state of Orissa in India

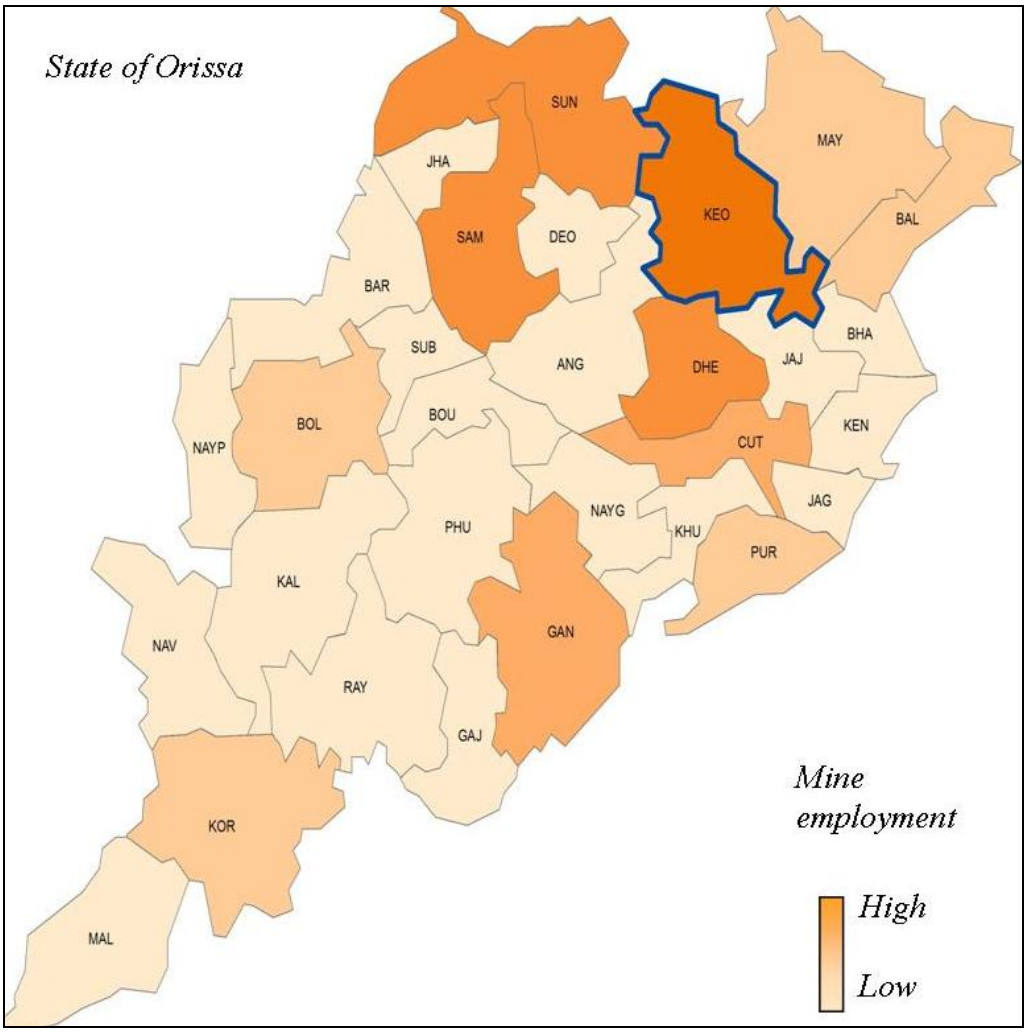


Figure 4.3 Keonjhar district in Orissa (highlighted)
Keonjhar district has the largest number of mine workers in the state of Orissa. 31% of all mining employment in Orissa is in Keonjhar district.

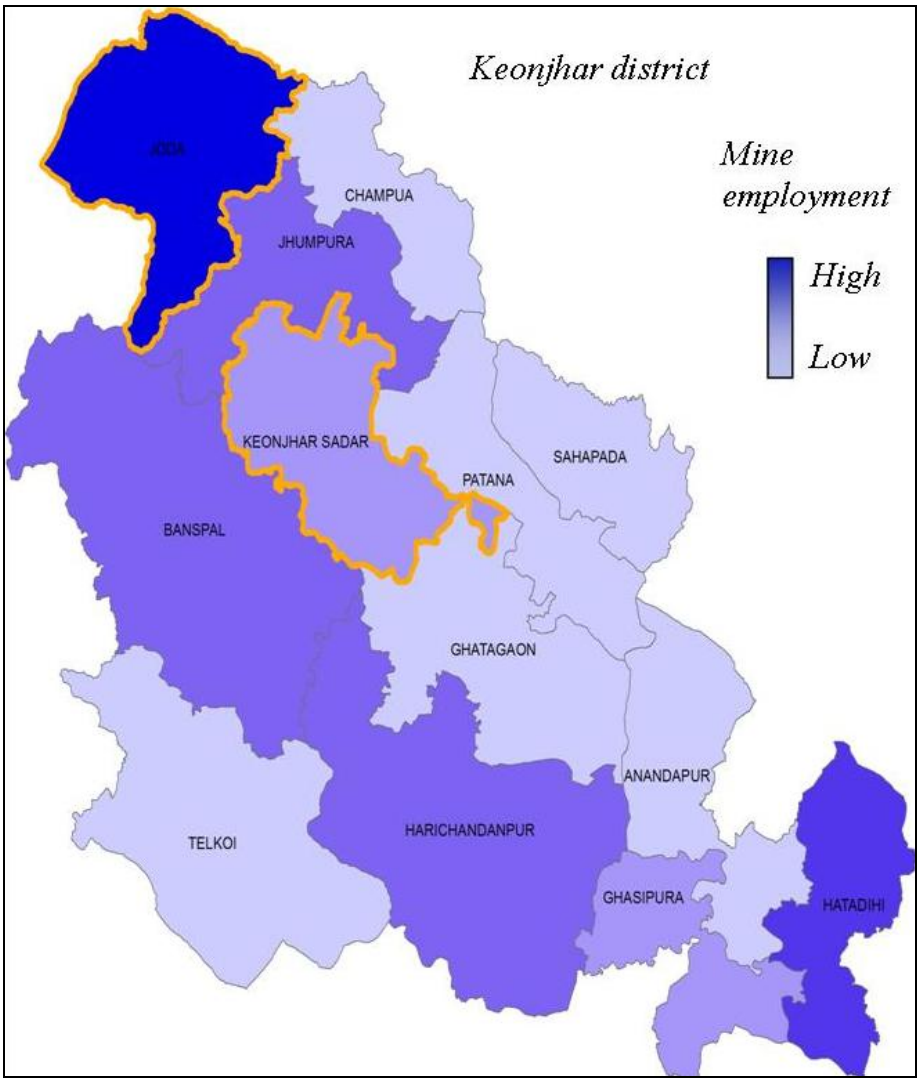


Figure 4.4 Two blocks included in the study – Joda and Keonjhar Sadar According to the national census in 1991, 68% of reported mine workers in the district were in Joda block while Keonjhar Sadar reported only 1% of mine workers.

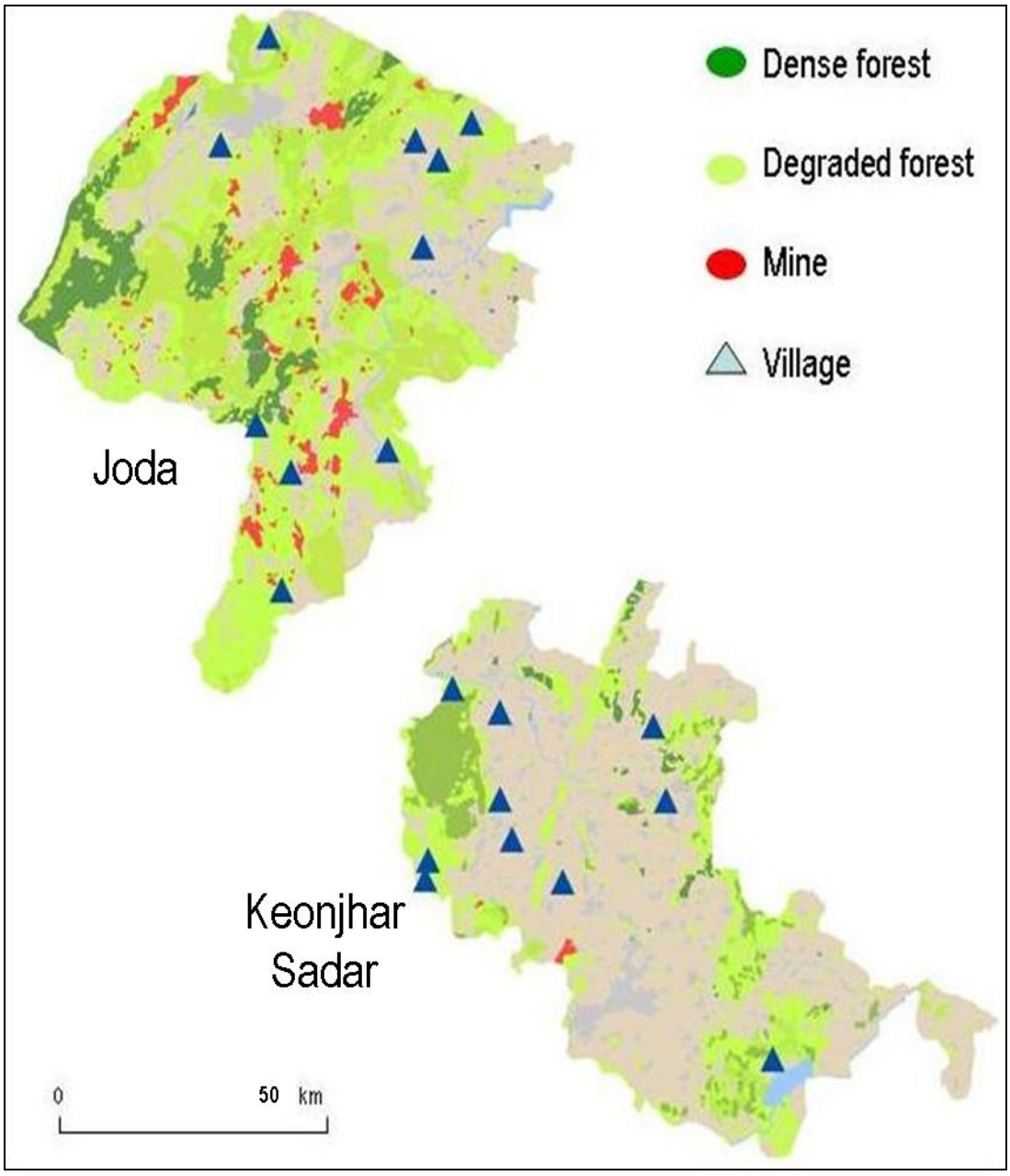


Figure 5.4 Classified land cover images for the two blocks Joda and Keonjhar Sadar. The GIS data on the location of the mines and villages were used to calculate two measures of exposure to iron ore mines – Euclidean distance to iron ore mines and number of mines in a 2km buffer around each village

Table 4.1. Descriptive statistics of household and individual level variable used in the analyses

Variable	Obs	Mean	Std. Dev.	Min	Max
Scheduled Caste	600	0.07	0.25	0	1
Scheduled Tribe	600	0.68	0.47	0	1
Log net firewood consumed (kg)	600	3.85	1.37	0	6.58
Participation in number of social organizations	600	1.79	1.28	0	6
Number rooms in house	600	2.70	1.48	1	11
Average amount of irrigated land around village (acres in a 2 km village buffer)	600	2.78	3.72	0	12
Change in forest cover within 2km village buffer (2004 area – 1989 area)	600	1.24	8.43	-19.62	24.86
Log distance to paved road (km)	600	2.87	1.05	0.69	5.20
Log distance to health center (km)	600	3.41	1.06	0.69	5.08
Log distance to market center (km)	600	3.81	0.78	0.0	5.19
Distance to iron ore mine (km)	600	7.33	6.11	0.21	20.92
Cash income from mines (Rs)	600	6979.5	12383.9	0	108000
Use of improved stoves (dummy)	600	0.01	0.10	0	1
Use of partitioned kitchen (dummy)	600	0.53	0.50	0	1
Use of bed nets (dummy)	600	0.53	0.50	0	1
Participate in micro-credit organizations (dummy)	600	0.12	0.33	0	1
Age of individuals (years)	2494	26.92	17.98	0.23	105
Education of individuals	2494	2.97	4.04	0	18
Average hours working in mines	2494	1.66	2,67	0	12

Table 4.2. Descriptive statistics of health outcome indicators for the full sample, and the two blocks separately

Variable	Full sample				Joda (*High exposure*)		Keonjhar (*Low exposure*)		Population weighted mean	Correlation with distance to iron ore mine
	Mean	SD	Min	Max	Mean	SD	Mean	SD		
Count of ARI incidence*	1.0	1.2	0	6	1.2	1.3	0.8	1.2	1.0	-0.16 †
Count of Malaria incidence*	1.6	1.4	0	10	1.5	1.2	1.8	1.6	1.6	0.12 †
Expenditure on ARI (Rs)	143.8	450.3	0	8750	158.5	287.0	129.0	568.8	146.1	-0.02
Expenditure on Malaria* (Rs)	544.4	1110.1	0	17350	678.5	1349.0	410.2	782.9	557.2	-0.09 †
Workdays lost due to ARI	4.8	9.8	0	90	5.5	9.0	4.0	10.6	5.1	-0.09 †
Workdays lost due to Malaria*	16.0	17.4	0	160	19.5	19.6	12.5	13.9	17.0	-0.16 †

* t-test indicating means of Joda and Keonjhar blocks are significantly different at 5% level

† significance at 5% level

Table 4.3. Distribution of health indicators across the villages (villages are arranged in ascending order according to Euclidean distance to mines)

		Joda (*High exposure*)										Keonjhar Sadar (*Low exposure*)									
Distance to mine from village (km)		0.2	0.8	0.9	1.2	1.4	2	2.4	3.3	3.8	4	6.4	9.3	10	10	11	13	14	15	17	21
Count of ARI incidence	0.99	-	+	+	+	+	-	+	-	+	+	-	+	-	-	-	+	+	-	-	-
Count of Malaria incidence	1.65	-	+	+	-	-	-	-	+	-	-	-	+	-	+	+	+	+	+	+	+
Expenditure on ARI (Rs)	143.78	-	+	+	-	-	-	-	-	+	+	-	-	-	-	-	+	+	+	-	-
Expenditure on Malaria (Rs)	551.28	+	+	+	+	-	-	-	+	-	+	-	-	-	-	-	-	-	-	-	+
Workdays lost due to ARI	4.77	-	+	+	+	+	-	-	-	-	+	-	+	+	-	-	+	+	+	-	-
Workdays lost due to Malaria	16.34	-	+	+	-	-	-	-	+	+	+	-	-	-	-	-	-	-	-	-	-

+ indicates that village mean is greater than population mean; - indicates that village mean is lower than population mean

Table 4.4. Description of health indicators by sub-groups based on mine employment

Variable	No member in family works in mine		Other member in family working in mine		Only individuals in family working in mine	
	mean	*st error*	*mean*	*st error*	*mean*	*st error*
Reported ARI	0.21	0.01	0.23	0.01	0.22	0.02
Workdays lost to ARI	1.04	0.09	1.07	0.16	0.92	0.16
Expenditure on ARI (Rs.)	33.64	5.07	28.74	3.60	28.62	5.85
Reported Malaria	0.36	0.01	0.32	0.02	0.32	0.03
Workdays lost to Malaria	1.34	0.07	1.97	0.19	1.96	0.24
Expenditure on Malaria (Rs.)	105.18	9.31	110.49	10.49	151.79	39.08
observations	1867		799		283	

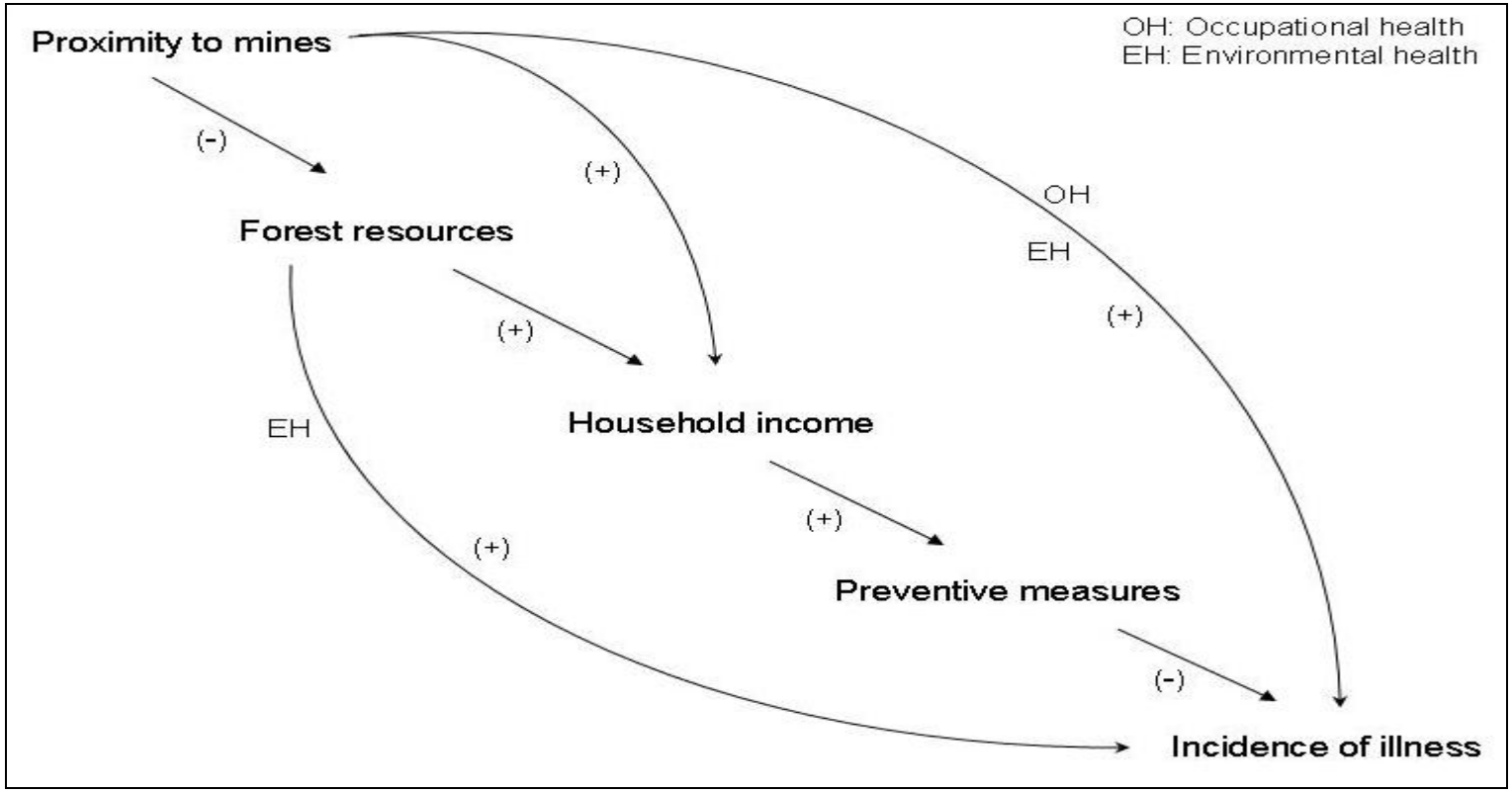


Figure 4.6 Conceptual framework to analyze the impact of mines on health for the population living in close proximity

The arrows indicate a causal link between different elements in the framework. A (-) sign indicates a negative relationship in the causal chain – for example, mining often involves clearing forests for excavation and thus proximity to mines reduces the availability of forest resources. On the other hand, an example of hypothesized positive relation between higher disposable income and higher adoption of prevention measures is indicated by a (+) sign.

Table 4.5 Probit model for incidence of ARI and malaria among individual family members

	probit for ARI			probit for malaria		
	dy/dx	*st. error* [a]	*p-val*	*dy/dx*	*st. error* [a]	*p-val*
Dummy for male	0.034	0.057	0.533	0.054	0.054	0.320
Age	0.000	0.002	0.841	0.002	0.002	0.231
Scheduled Caste	-0.116	0.179	0.516	-0.051	0.121	0.671
Scheduled Tribe	-0.219	0.116	0.06	-0.178	0.093	0.056
Log of firewood consumed	0.009	0.033	0.783			
Average irrigated land around village				-0.034	0.008	0.000
Change in forest cover in a 2k buffer				0.004	0.005	0.353
Log of distance to road	-0.057	0.054	0.296	-0.028	0.052	0.592
Log of distance to health center	0.033	0.046	0.474	0.017	0.037	0.643
Days worked in mine [#]	-0.001	0.001	0.045	0.001	0.001	0.343
Distance to iron ore mine	-0.023	0.008	0.006	0.019	0.007	0.003
Dummy for improved stove	-0.757	0.475	0.101			
Dummy for partition in kitchen	-0.230	0.096	0.017			
Dummy for use of mosquito nets				-0.118	0.067	0.076
Number of observations		2949			2949	
AIC		35241.6			35864.4	
Log pseudo likelihood		-17593.8			-17904.2	

Days worked in mines instrumented in a 2SLS model. Instruments used are distance to iron ore mine, average number of hours worked in wage employment, dummy if land owned and years of education.

a. Clustered robust standard errors by village

Table 4.6 3SLS model for workdays lost due to ARI and malaria

	Workdays lost to ARI			Workdays lost to malaria		
	coeff	*st err* [a]	*p-val*	*coeff*	*st err* [a]	*p-val*
Dummy for male	-0.042	0.163	0.790	0.063	0.156	0.681
Age	0.007	0.004	0.110	0.005	0.004	0.238
Scheduled Caste	-0.662	0.320	0.039	-0.310	0.308	0.305
Scheduled Tribe	-0.794	0.174	0.000	-0.490	0.173	0.005
Log of firewood consumed	-0.030	0.055	0.587			
Average irrigated land around village				-0.036	0.020	0.076
Change in forest cover in a 2k buffer				0.024	0.009	0.009
Log of distance to road	-0.065	0.073	0.368	-0.018	0.072	0.802
Log of distance to health center	0.120	0.076	0.117	0.077	0.076	0.318
Days worked in mine	-0.001	0.002	0.549	0.001	0.002	0.536
Distance to iron ore mine	-0.026	0.014	0.066	-0.085	0.014	0.000
Dummy for improved stove	-0.909	0.734	0.216			
Dummy for partition in kitchen	-0.289	0.150	0.054			
Dummy for use of mosquito nets				-0.254	0.151	0.090
constant	1.424	0.434	0.007	2.342	0.471	0.000
Chi-squared	35.34			0.03	79.83	
Prob > Chi-Sq	0.000				0.000	
Days worked in mine						
Distance to iron ore mine	-1.441	0.188	0.000			
Daily hours in wage employment	14.052	0.396	0.000			
Dummy if land owned	-7.007	2.332	0.003			
Years of education	0.712	0.267	0.008			
Constant	11.100	2.091	0.000			
Chi-squared	1419.64					
Prob > Chi-Sq	0.000					
Number of observation	2949					

a Clustered robust standard errors by village.

Days worked in mines instrumented in a 3SLS model. Instruments used are distance to nearest iron ore mine, average number of hours worked in wage employment, dummy if land owned and years of education.

Adding more variables like Scheduled caste, Scheduled tribe, age and sex to the first stage equation of days worked in mines did not change the signs and significance of coefficients in the equation of workdays lost.

Estimating the same models with the restricted samples where workdays lost due to ARI and malaria was <15 did not produce any significant changes to the results.

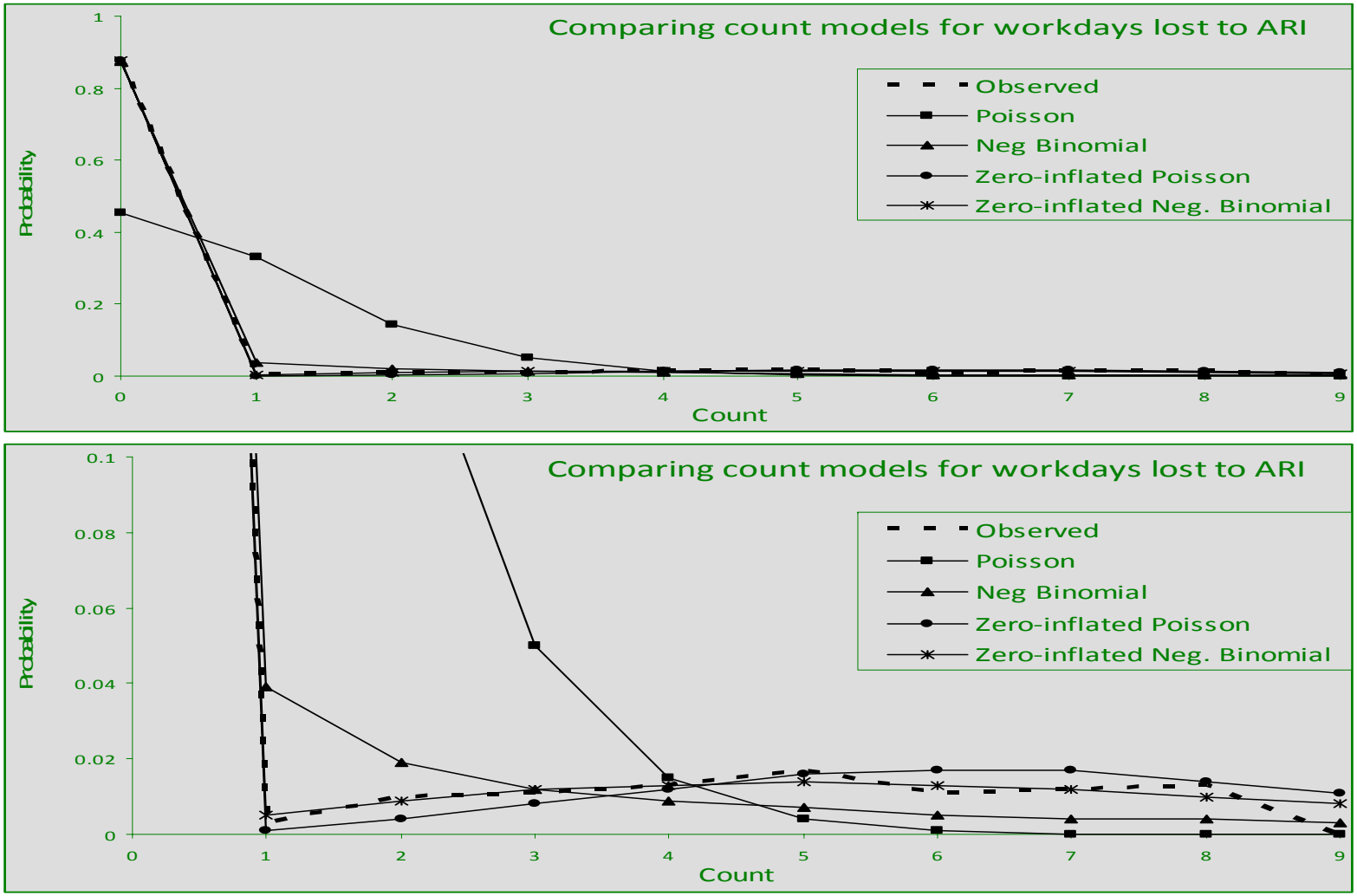


Figure 4.7 Poisson, Negative Binomial, Zero-inflated Poisson and Zero-inflated Negative Binomial models with observed distribution of workdays lost due to ARI

Table 4.7 Comparing count models for workdays lost due to ARI

	Poisson		Neg. Binomial		Zero-inflated Poisson		Zero-inflated Neg. Binomial	
Dummy for male	+	**	+	**	+	**	+	**
Age	-		-		-		+	
Scheduled Caste	-	*	-	*	-		-	
Scheduled Tribe	-	**	-	**	-		-	
Log of firewood consumed	-	**	-		-	*	-	*
Log of distance to road	-		-	*	-		+	
Log of distance to health center	+	**	+	**	+	**	+	**
Days worked in mine	+		+		-		-	
Distance to iron ore mine	-		-		-		-	
Dummy for improved stove	-		-	*	-	**	-	**
Dummy for partitioned kitchen	-	**	-	**	-		-	
constant	-		-		+		+	
N	2935		2935		2935		2935	
Log likelihood	-6112		-2333		-2132		-2055	
Bayesian Information Criterion	12321		4570.4		4399.3		4253.9	
Akaike Information Criterion	12249		4492.6		4297.5		4146.2	
Dispersion parameter	na		**		**		**	
Vuong Statistic					21.52	**	11.15	**

**, * indicates significance at the 5% and 15% respectively

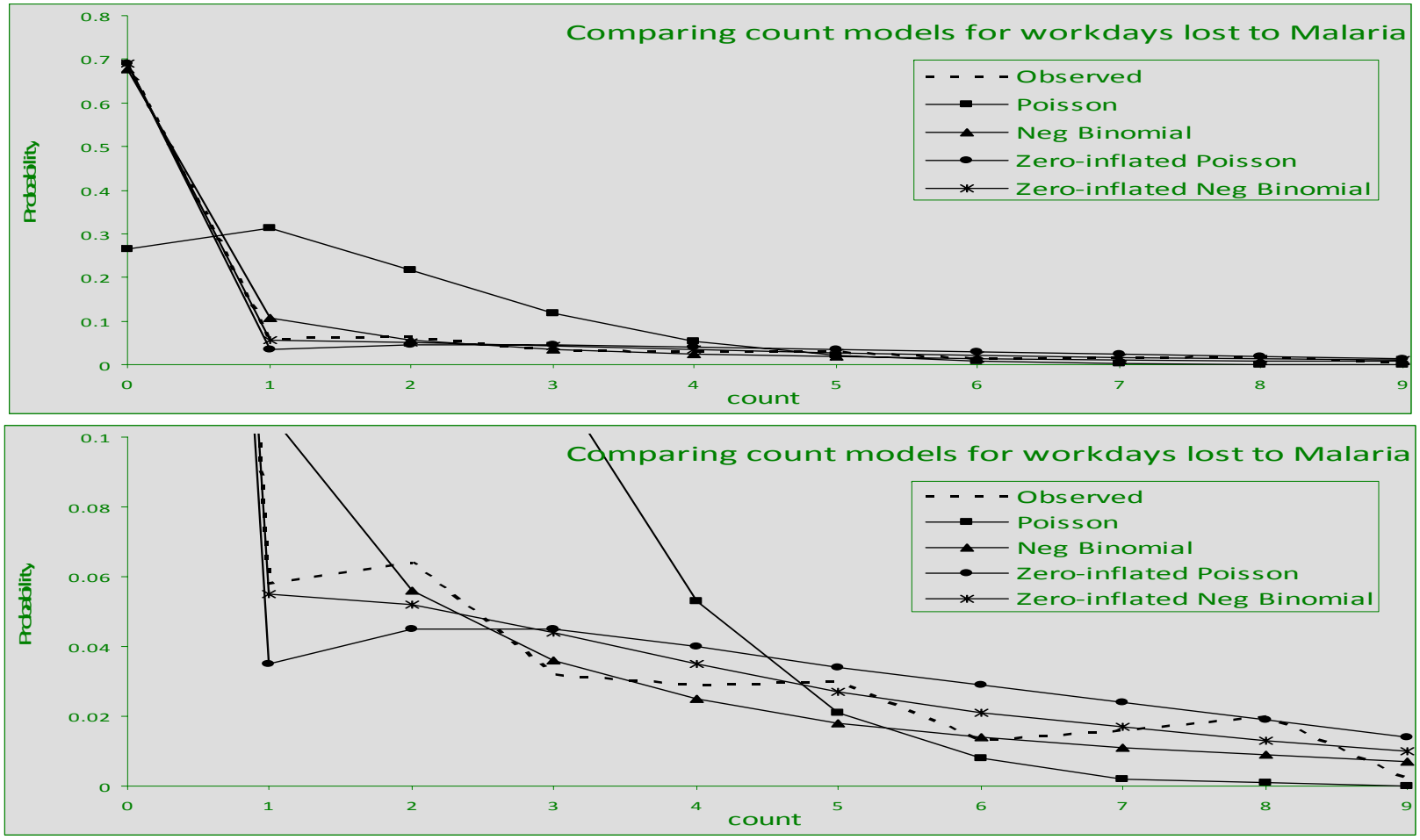


Figure 4.8 Poisson, Negative Binomial, Zero-inflated Poisson and Zero-inflated Negative Binomial models with observed distribution of workdays lost due to Malaria

Table 4.8 Comparing count models for workdays lost due to Malaria

	Poisson		Neg. Binomial		Zero-inflated Poisson		Zero-inflated Neg. Binomial	
Dummy for male	+		+		-		-	
Age	+		+		-		-	
Scheduled Caste	-		-		+		+	
Scheduled Tribe	-	**	-	**	-		-	
Average % irrigated land in 2kbuffer	-	**	-		+		+	*
Decrease in forest cover	+	**	+	**	+	**	+	**
Log of distance to road	-		+		+		+	
Log of distance to health center	+		+		+		+	
Days worked in mine	+		+		+		+	
Distance to iron ore mine	-	**	-	**	-	**	-	**
Dummy for use of mosquito nets	-	**	-	**	-		-	*
constant	+	**	+	**	+	**	+	**
N	2944		2944		2944		2944	
Log likelihood	-7489.1		-4095.3		-4099.2		-3903.9	
Bayesian Information Criterion	15092		8294.5		8334.2		7951.5	
Akaike Information Criterion	15020.1		8216.6		8232.4		7843.7	
Dispersion parameter	na		**		**		**	
Vuong Statistic					25.91	**	10.36	**

**, * indicates significance at the 5% and 15% respectively

Table 4.9 Results from Zero-inflated Negative Binomial model for workdays lost to ARI and Malaria

	Workdays lost to ARI			Workdays lost to Malaria		
	coeff	*st error* [b]	*p-val*	*coeff*	*st error* [b]	*p-val*
Dummy for male	-0.140	0.060	0.02	0.045	0.077	0.56
Age	0.001	0.003	0.76	0.001	0.002	0.73
Scheduled Caste	-0.234	0.126	0.06	0.028	0.123	0.82
Scheduled Tribe	-0.090	0.086	0.29	-0.124	0.147	0.40
Log of firewood consumed	-0.055	0.031	0.07			
Average % irrigated land in 2kbuffer				0.031	0.022	0.15
Decrease in forest cover				0.015	0.004	0.00
Log of distance to road	0.034	0.026	0.19	0.018	0.050	0.72
Log of distance to health center	0.102	0.049	0.04	0.045	0.053	0.39
Days worked in mine	-0.004	0.007	0.50	0.000	0.001	0.84
Distance to iron ore mine	-0.003	0.001	0.42 [a]	-0.074	0.013	0.00
Dummy for improved stove	-0.116	0.074	0.12			
Dummy for partitioned kitchen	-0.019	0.086	0.83			
Dummy for use of mosquito nets				-0.111	0.125	0.37
constant	1.846	0.241	0.00	1.815	0.389	0.00
Inflation equation:						
Household below poverty line	0.462	0.107	0.00	0.160	0.119	0.18
Log of distance to health center	-0.064	0.087	0.46	0.097	0.050	0.05
Dummy for male	0.005	0.088	0.96	0.147	0.074	0.05
Age	0.007	0.005	0.12	-0.002	0.003	0.52
Education	0.035	0.016	0.03	-0.028	0.020	0.15
Scheduled Caste	0.161	0.347	0.64	0.506	0.244	0.04
Scheduled Tribe	0.482	0.195	0.01	0.218	0.209	0.30
Family size	0.195	0.039	0.00	0.073	0.037	0.05
constant	0.266	0.433	0.54	-0.318	0.324	0.33

a. This is barely significant at the 15% level when the logarithm of distance to nearest iron ore mine is used.
b. Clustered robust standard errors by village.

Table 4.10 Probit models of adoption of preventive measures

	Use of bed nets			Use of improved stoves [b]			Better kitchen construction		
	dy/dx	*st err*[a]	*p-val*	*dy/dx*	*st err*[a]	*p-val*	*dy/dx*	*st err*[a]	*p-val*
Dummy for land ownership	0.143	0.079	0.06	0.238	0.001	0.02	-0.002	0.051	0.95
Dummy for participation in micro-credit group [c]	-0.123	0.074	0.09				0.013	0.093	0.88
Adoption by other members in same village	0.02	0.005	0.00	-0.113	0.304	0.44	0.007	0.006	0.24
Participate in social organizations	0.089	0.035	0.01	-0.082	0.081	0.15	0.002	0.041	0.96
Log of distance to markets	-0.001	0.031	0.97	-0.278	0.154	0.59	-0.008	0.027	0.75
Number of rooms in the house	0.135	0.028	0.00	0.097	0.217	0.19	-0.171	0.019	0.00
Days worked in mines [b]	0.004	0.008	0.64	0.002	0.041	0.02	0.003	0.007	0.60
Number of observations	2949			528			2949		
Wald Chi-Sq.	106.56			25.83			103.63		
Log pseudolikelihood	-1629.31			-5697.66			-1752.84		
Wald test for exogeneity: Prob > Chi_sq	0.89			0.01			0.84		

a. Clustered robust standard error by villages
b. Days worked in mines is treated as endogenous and instruments used are – distance to iron ore mine and average amount spent by household members in wage employment.
c. None of the families that adopted improved stoves participated in micro-credit organizations. The variable drops out of the equation.

CONCLUSION

Whether public policies achieve the desired objectives critically depend on how appropriately contextual factors that influence individual decisions are taken into account. Not only is it important to identify these contextual factors, but the feedback between these factors may give rise to externalities that also have crucial policy repercussions – either through (1) generating unintended consequences that undermine the welfare potential or (2) ignoring complementarities between factors that could amplify the attainment of the objectives. These externalities typically remain unaccounted for in developing regions that are characterized by imperfect markets and weak institutions, resulting in advertent policy outcomes. In the simplistic conceptual framework of sustainable development presented in the introduction, these contextual factors could be categorized into the three conceptual elements – society, environment and the economy.

The three case studies analyzed in the dissertation produce evidence in favor of the presence of three such externalities. In the first case study, farmer associations in the Brazilian Amazon frontier are found to be important agencies for transfer of knowledge regarding agricultural land use alternatives. The collective knowledge shared among members belonging to these farmer associations is often the only source of information for individual farmers regarding these practices. With the commonly held belief that adoption of sustainable agriculture reduces the propensity of small farmers to deforest, these associations provide policymakers the opportunity to promote land use systems that

are well-adapted to local environmental conditions and profitable. In the second case study, the environmental consequences of improving rural commodity markets in the Amazon frontier are examined. Integrating rural markets for agricultural products has been a central objective in the context of rural development. However, there have been few empirical analyses of whether farmers in response to such market development intensify agricultural production, or if they engage in more extensive practices. While market expansion is exogenous to the individual farmer, the subsequent changes in farmgate commodity prices strongly influence individual land use decisions. The results for the analyses show that while expansion of local milk industry had significant increase in milk price that farmers received, they have simultaneously engaged in intensification and extensification of their pasture systems in response to the pecuniary externality. With conversion of cleared land to pastures being a dominant land use practice among many small farmers in the Amazon, the policy implication emerging from the analyses highlights the fact the economic incentives alone may not wean farmers away from extensifying pastures and increasing deforestation. One possibility to avoid such environmental consequences could be to couple economic policy with more strict environmental regulations on deforestation. In the third case study, a classic environment externality is examined where iron ore mining operations are suspected of causing adverse local health outcomes. Proponents of the mining industry emphasize the local development potential, both short term (higher income benefits from employment in mines) and long term (roads, electricity). However, pollution and environmental

degradation due to mining activities also cause negative health impacts that undermine the purported benefits. Using distance to mines as a proxy for exposure to mining activities, villagers living closer to mines reported higher incidences of acute respiratory illness and higher number of workdays lost due to malaria. These findings make it imperative to account for these negative welfare outcomes in assessments of the local development potential of the mining industry.

As mentioned, it is important to take account of these externalities as they could produce both desirable as well as negative public policy impacts. In the first case study, evidence in favor of information externality opens the policy option of promoting sustainable agricultural systems through farmer cooperatives. The social multiplier effect indicated by the positive endogenous social interaction effect among members of farmer associations can amplify the rate of adoption of new technology following intervention programs. In the second case study, expanded markets have improved economic conditions of farmers participating in the milk trade, but the impact of the economic incentives on encouraging more intensive pasture management has been limited. Increased deforestation through extensive pasture management may become an unintended consequence of a myopic economic policy unless additional safeguards are instituted to prevent indiscriminate clearing of the rainforest. The third case study refers to an environmental externality, and invokes a more active participation of the state to

internalize the negative impacts through a more equitable benefit-sharing arrangement that adequately compensates the local population for poor health outcomes.

Methodologically, the characterization of the externalities would remain incomplete without explicitly considering spatial attributes of the problem. In the first case study, it was critical to control for interaction among farmers who are physical neighbors to identify any social interaction that is not limited by spatial location of farmers. Expansion of the milk market in the second case study did not affect each farmer uniformly. Location of farmers vis-à-vis the milk plants were critical factors as transportation costs and competition among milk plants were important determinants of farmgate milk price that was found to affect pasture management choices of farmers. Without explicit spatial information, the variation in farmers' access to new milk plants would have been less precise. In the third case study, distance-based metric of exposure to mining activities was the metric used in absence of field-based measurements of pollution that were resource-intensive. Again, without the spatial information on location of villages and the mining areas, only subjective responses of villagers who were interviewed could be used for mine exposure. In general, public policy is targeted towards specific populations that are spatially well-defined. Taking into account these spatial configurations not only provides more context to policy analyses, but also provides certain econometric advantages in terms of additional variables and instruments. The three case studies in the dissertation contributes to the growing emphasis on

combining traditional household surveys with spatial data obtained through satellite imagery and Geographic Positioning Systems that combines people with pixels.

References

Introduction

Anselin, L. 2002. "Under the hood: issues in the specification and interpretation of spatial regression models." *Agricultural Economics*, Vol. 27, 247-267.

Baumol, W. J. and Oates, W. E. 1988. "*The theory of environmental policy*." Cambridge University Press, second edition.

Daly, H. 1990. "Towards some operational principles of sustainable development." *Ecological Economics*, 2, 1-6.

Dasgupta, P. 2005. "Economics of social capital." *The Economic Record*, Vol. 81 (255), S2-S21.

Giddings, B., Hopwood, B. and O'Brien, G. 2002. "Environment, economy and society: fitting them together into sustainable development." *Sustainable Development*, 10, 187–196.

International Council for Local Environmental Initiative (ICLEI). 1996. "*The Local Agenda 21 planning guide: an introduction to Sustainable Development Planning*." ICLEI: Toronto.

Jaffe, A. B., Newell, R. G. and Stavins, R. N. 2005. "A tale of two market failures: Technology and environmental policy." *Ecological Economics*, 54, 164-174.

Kates, W. R. et al. 2001. “Environment and development: Sustainability Science.” *Science* 27. Vol. 292 (5517), 641 – 642.

Katz, M. L. and Shapiro, C. 1985. “Network Externalities, Competition, and Compatibility.” *American Economic Review*. Vol. 75(3), 424-440.

Liverman, D. M. 1998. “*People and pixels: linking remote sensing and social science.*” Committee of the Human Dimensions of Global Change, National Research Council, National Research Council (U.S.).

Munasinghe, M., 1993. “*Environmental Economics and Sustainable Development*.” World Bank, Washington, DC.

Ottaviano, G. and Thisse, J.F. 2001. “On economic geography in economic theory: increasing returns and pecuniary externalities.” *Journal of Economic Geography*. Vol 1, 153-179.

Pezzey, J. 1992. “Sustainable development concepts: an economic analysis.” *World Bank Environment Paper*; no. 2.

Sachs, J. D. 2004. “Sustainable Development.” *Science* 30, Vol. 304 (5671), p. 649.

Schirnding, v. J. 2002. “*Health in sustainable development: role of indicators*.” World Health organization, Geneva. http://www.who.int/wssd/resources/indicators/en/ (accessed on May 19, 2008).

Stanton, E. 2007. “The Human Development Index: A History.” *Political Economy Research Institute. Working Paper Series*, Number 127.

World Health Organisation (WHO). 1997. "*City Planning for health and sustainable development.*" WHO Regional Office Europe: Copenhagen.

World Commission on Environment and Development, 1987. "*Our common future*." Oxford University Press. (Brundtland report).

United Nations report. 2001. "*Commission on Sustainable Development acting as the preparatory committee for the World Summit on Sustainable Development*." Economic and Social Council, N0129082.

Impact of Social Interaction on Land Use in the Amazon Frontier

Alves, D. S., et al. 1999. "Characterizing landscape changes in Central Rondônia Using Landsat TM imagery." *International Journal of Remote Sensing*, 20: 2877-2882.

Anselin, L. 2002. "Under the hood issues in the specification and interpretation of spatial regression models." *Agricultural Economics*, 27: 247-267.

Arima, E., P. Barreto, and M. Brito. 2006 "Cattle ranching in the Amazon: Trends and implications for environmental conservation." Amazon Institute of People and the Environment (IMAZON).

Bandiera, O., and I. Rasul. 2006. "Social networks and technology adoption in Northern Mozambique." *The Economic Journal*, 116: 869-902.

Bebbington, A. 1997. "Social capital and rural intensification: Local organization and islands of sustainability in the Rural Andes." *The Geographic Journal,* 163, no. 2: 189-197.

Browder, J., M. Pedlowski, and P. Summers. 2004. "Land use patterns in the Brazilian Amazon: Comparative farm-level evidence from Rondonia." *Human Ecology*, 32, no. 2: 192-224.

Case, A. 1992. "Neighborhood influence and technological change." *Regional Science and Urban Economics,* 22: 491-508.

Caviglia-Harris, J. L. 2004. "Household production and forest clearing: The role of farming in the development of the Amazon." *Environment and Development Economics,* 9, no. 2: 181-202.

Caviglia-Harris, J. L. 2003 "Sustainable agricultural practices in Rondonia, Brazil: Do local farmer organizations affect adoption rates?" *Economic Development and Cultural Change,* 52, no. 1: 23-50.

Chomitz, K. M., and D. A. Gray. 1996. "Roads, land use, and deforestation: A spatial model applied to Belize." The World Bank Economic Review 10: 487-512.

Conley, T., and E. Ligon. 2002. "Economic distance and cross-country spillovers." *Journal of Economic Growth,* 7: 157-187.

Crane, J. 1991. "The epidemic theory of ghettos and neighborhood effects on dropping out and teenage childbearing." *American Journal of Sociology*, 96, no. 5: 1226-1259.

Diez Roux, A. V. 2001. "Investigating neighborhood and area effects on health." *American Journal of Public Health,* 19, no. 11: 1783-1789.

Durlauf, S. and Cohen-Cole, E. 2004. "*Social interaction models*." In Encyclopedia of social measurement, Kimberly Kempf-Leonard (ed). Academic Press.

Evans, W. N., W. E. Oates, and R. M. Schwab. 1992. "Measuring peer group effects: a study of teenage behavior." *Journal of Political Economy,* 100, no. 5: 966-991.

Fafchamps, M., and B. Minten. 2002. "Returns to social capital among traders." *Oxford Economic Papers,* 54: 173-206.

Fearnside, P. 1997. "Environmental services as a strategy for sustainable development in Rural Amazonia." *Ecological Economics,* 20, no. 1: 53-70.

Feder, G., R. E. Just, and D. Zilberman. 1985. "Adoption of agricultural innovations in developing countries: a survey." *Economic Development and Cultural Change,* 33: 55–298.

Foster, A., and M. Rosenzweig. 1995. "Learning by doing and learning from others: Human capital and technical change in agriculture." *Journal of Political Economy,* 103: 1176-1209.

Fujisaka, S., G. Escobar, and E. Veneklaas. 1998. "Plant community diversity relative to human land uses in an Amazon forest colony." *Biodiversity Conservation,* 7: 41-57.

Fujisaka, S., and D. White. 1998. "Pasture or permanent crops after slash-and-burn cultivation? Land-use choice in three Amazon colonies." *Agroforestry Systems,* 42: 45-59.

Gaviria, A., and S. Raphael. 2001. "School-based peer effects and juvenile behavior." *The Review of Economics and Statistics,* 83, no. 2: 257-268.

Geist, H. J., and E. F. Lambin. 2002. "Proximate causes and underlying driving forces of tropical deforestation." *BioScience,* 52, no. 2: 143-150.

Glaeser, E. L., B. I. Sacerdote, and J. A. Scheinkman. 2003. "The social multiplier." *Journal of the European Economics Association,* 1, no. 2-3: 507-548.

Henderson, V., Mieszkowski, P., Sauvageau, Y. 1978. "Peer group effects and educational production functions." *Journal of Public Economics,* 10: 97-106.

Hogan, D. J. "Sistemização das informações censitárias sobre migração: Estado de Rondônia - dados demográficos." UNICAMP.

Ioannides, Y. M., and J. E. Zabel. 2003. "Neighborhood effects and housing demand." *Journal of Applied Econometrics,* 18: 563-584.

Isham, J. 2002. "The effect of social capital on fertilizer adoption: Evidence from rural Tanzania." *Journal of African Economies,* 11, no. 1: 39-60.

Jones, D., et al. 1995. "Farming in Rondônia." *Resource and Energy Economics,* 17: 155-188.

Jones, S. R. G. 1990. "Worker interdependence and output: The Hawthorn studies reevaluated." *American Sociological Review,* 55, no. 2: 176-190.

Laurance, W. F., A. K. M. Albernaz, and C. da Costa. 2001. "Is deforestation accelerating in the Brazilian Amazon?" *Environmental Conservation,* 28, no. 4: 305-311.

Lee, D. R., et al. 2001. "*Assessing tradeoffs and synergies among agricultural intensification, economic development and environmental goals: Conclusions and implications for policy*," ed. D. R. Lee, and C. B. Barrett. New York, CABI, pp. 451-464.

Lee, L. F. 2007. "Identification and estimation of econometric models with group interactions, contextual Factors and fixed Effects." *Journal of Econometrics,* 140: 333-374.

Leenders, R. T. A. J. 2002. "Modeling social influence through network autocorrelation: Constructing the weight matrix." *Social Networks,* 24: 21-47.

LeSage, J. P. 1999. *The Theory and Practice of Spatial Econometrics*.

Luke, N., and K. Munshi. 2007. "Social affiliation and the demand for health services: Caste and child health in South India." *Journal of Development Economics,* 83, no. 2: 256-279.

Manski, C. 1993"Identification of endogenous social interaction effects: The reflection problem." *Review of Economic Studies,* 60: 531-542.

Marquette, C. M. 2006. "Settler welfare on tropical forest frontiers in Latin America." *Population and Environment*, Vol. 27, 397-444.

McIntyre, S., S. Maciver, and A. Sooman. 1993. "Area, class and health: Should we be focusing on places or people?" *Journal of Social Policy*, 22, no. 2: 213-234.

Moffitt, R. A. 2001. Policy interventions, low-level equilibria, and social interactions, ed. S. N. Durlauf, and H. P. Young. Massachusetts, MIT Press, pp. 45–82.

Munshi, K. 2004. "Social learning in a heterogeneous population: Technology diffusion in the Indian green revolution." *Journal of Development Economics*, 73: 185-213.

Naughton-Treves, L. 2004. "Deforestation and carbon emissions at tropical frontiers: A case study from the Peruvian Amazon." *World Development,* 32, no. 1: 173-190.

Nepstad, D. C., C. Uhl, and E. A. S. Serrão. 1991. "Recuperation of a degraded Amazonian landscape: Forest recovery and agricultural restoration." *Ambio*, 20: 248-255.

Pacheco, P. 2005. "Populist and capitalist frontiers in the Amazon: diverging dynamics of agrarian and land use change." Doctoral dissertation, Clark University.

Padel, S. 2001. "Conversion to organic farming: A typical example of the diffusion of an innovation?" *Sociologia Ruralis,* 41, no. 1: 40-61.

Pattanayak, S., and D. Butry. 2005. "Spatial complementarity of forests and farms: Accounting for ecosystem services." *American journal of Agricultural Economics*, 87, no. 4: 995–1008.

Perz, S. G. 2004. "Are agricultural production and forest conservation compatible? Agricultural diversity, agricultural incomes and primary forest cover among small farm colonists in the Amazon." *World Development,* 32, no. 6: 957-977.

Perz, S. G. 2003. "Social determinants and land use correlates of agricultural technology adoption in a forest frontier: A case study in the Brazilian Amazon." *Human Ecology,* 31, no. 1: 133-165.

Perz, S. G., R. T. Walker , and M. M. Caldas. 2006. "Beyond population and environment: household demographic life cycles and land use allocation among small farms in the Amazon." *Human Ecology,* 34: 829-849.

Ramirez, A., C. Sere, and J. Uquillas. 1992. "An economic analysis of improved agroforestry practices in the Amazon lowlands of Ecuador." *Agroforestry Systems,* 17: 65-86.

Reis, E. J., and S. Margulis. 1994. "*An econometric model of Amazon deforestation*." The causes of tropical deforestation: the economic and statistical analysis of factors giving rise to the loss of tropical forests. Edited by K. Brown, and D. W. Pearce: University College London Press, London, U.K.

Rogers, E. M. "*Diffusion of Innovations*." 4th edition ed. New York: The Free Press, 1995.

Romani, M. "Love Thy Neighbor? Evidence from ethnic discrimination in information Sharing within villages in Côte d'Ivoire. 2003. " *Journal of African Economies,* 12, no. 4: 533-563.

Sacerdote, B. 2001. "Peer effects with random assignment: results for Dartmouth roommates." *Qaurterly Journal of Economics*, 116, no. 2: 681–703.

Sampson, R. J., J. D. Morenoff, and G. Gannon-Rowley. 2002. "Assessing neighborhood effects": Social processes and new directions in research." *Annual Review of Sociology,* 28: 443-478.

Serrão, E. A. S., and J. Toledo. 1992. "*Sustaining pasture-based production systems for the humid tropics,*" ed. T. E. Downing, Pearson, H.A. and Garcia-Downing, C. Boulder, Westview Press, pp. 257-280.

Soetevent, A. R. 2006. "Empirics of the identification of social interactions; an evaluation of the approaches and their results." *Journal of Economic Surveys,* 20, no. 2: 193-228.

Vosti, S., J. Witcover, and C. L. Carpentier. 2002. "*Agricultural intensification by small-holders in the Western Brazilian Amazon - from deforestation to sustainable land use*." International Food Policy Research Institute IFPRI, Washington DC.

Walker, R., et al. 2002. "Land-use and land-cover change in forest frontiers: The role of household life cycles." *International Regional Science Review,* 25: 169-199.

Alfaia, S. S., et al. 2004. "Evaluation of soil fertility in smallholder agroforestry systems and pastures in western Amazonia." *Agriculture, Ecosystems & Environment,* 102, no. 3: 409-414.

Almeida, A. L. O. 1992. "*The colonization of the Amazon.*" University of Texas Press.

Almeida, O., and J. S. Campari. 1996. "*Sustainable settlement in the Brazilian Amazon.*" Oxford University Press.

Alves, D. S., et al. 1999. "Characterizing Landscape Changes in Central Rondonia Using Landsat TM Imagery." *International Journal of Remote Sensing,* 20: 2877-2882.

Andersen, L. E., et al. 2002. "*The dynamics of deforestation and economic growth in the Brazilian Amazon".* Cambridge: Cambridge University Press.

Angelsen, A., and D. Kaimowitz. 2001. "*When does technological change in agriculture promote deforestation?*". inTradeoffs or synergies? Agricultural intensification, economics development and the environment. Edited by C. B. Barrett, and D. R. Lee: CABI publishing, Wallingford, UK.

Arima, E., P. Barreto, and M. Brito. 2006. "*Cattle ranching in the Amazon: trends and implications for environmental conservation.*" Instituto do Homem e Meio Ambiente da Amazônia (IMAZON), Belém.

Arima, E., and C. Uhl. 1997. "Ranching in the Brazilian Amazon in a national context: Economics, policy, and practice." *Society & Natural Resources,* 10, no. 5: 433-452.

Asner, G. P., et al. 2004. "Pasture degradation in the central Amazon: linking changes in carbon and nutrient cycling with remote sensing." *Global Change Biology*, 10: 844-862.

Baidya Roy, S., and R. Avissar. 2002. "Impact of land use/land cover change on the regional hydrometeorology in Amazonia." *Journal of Geophysical Research*, 107(D20):8037.

Barretto, P., E. Arima, and M. Brito. 2005. "*Cattle ranching and challenges for environmental conservation in the Amazon*". Imazon.

Benjamin, D. 1992. "Household composition, labor markets, and labor demand: testing for separation in agricultural household models." *Econometrica*, 60: 287–322.

Browder, J. O., M. Pedlowski, and P. M. Summers. 2004. "Land use patterns in the Brazilian Amazon: Comparative farm-level evidence from Rondônia." *Human Ecology*, 32: 197-224.

Bulte, E. H., R. Damania, and R. López. 2007. "On the gains of committing to inefficiency: Corruption, deforestation and low land productivity in Latin America." *Journal of Environmental Economics and Management*, 54, no. 3: 277-295.

Campari, J. S. "*The economics of deforestation in the Amazon*". Edward Elgar publishing limited, Cheltenham, UK, 2005.

Carpentier, C. L., S. A. Vosti, and J. Witcover. 2000. "Intensified production systems on western Brazilian Amazon settlement farms: could they save the forest?" *Agriculture, Ecosystems & Environment,* 82, no. 1-3: 73-88.

Cattaneo, A. 2001. "*A general equilibirum analysis of technology, migration and deofrestation in the Brazilian Amazon*", ed. A. Angelsen, and D. Kaimowitz, CABI Publishing, Center for International Forestry Research (CIFOR).

Caviglia-Harris, J. L. 2005. "Cattle accumulation and land use intensification by households in the Brazilian Amazon." *Agricultural and Resource Economics Review,* 34, no. 2: 145-162.

Caviglia-Harris, J. L. 2004. "Household Production and Forest Clearing: The Role of Farming in the Development of the Amazon." *Environment and Development Economics,* 9, no. 2: 181-202.

Cerri, C. E. P., et al. 2007. "Predicted soil organic carbon stocks and changes in the Brazilian Amazon between 2000 and 2030." *Agriculture, Ecosystems & Environment,* 122, no. 1: 58-72.

Chomitz, K. M. 2007. "At loggerheads? agricultural expansion, poverty reduction, and environment in the tropical forests." *World Bank policy research report*.

Chomitz, K. M., and T. S. Thomas. 2003. "Determinants of land use in Amazônia: a fine-scale spatial analysis." *American Journal of Agricultural Economics,* 85, no. 4: 1016-1028.

Costa, P. F., and T. Rehman. 2005. "Unravelling the rationale of ‘overgrazing’ and stocking rates in the beef production systems of Central Brazil using a bi-criteria compromise programming model." *Agricultural Systems*, 83: 277-295.

de Castro, N. 2002. "Custos de transporte e produção agrígola no Brasil, 1970–1996." *Agricultura em São Paulo*, 49, no. 2: 87-109.

DeShazo, R. P., and J. R. DeShazo. 1995. "*An economic model of smallholder deforestation: a consideration of the shadow value of land on the frontie"r*, ed. Ø. Sandbukt, Centre for Development and the Environment, Oslo, pp. 153-166.

Desjardins, T., et al. 2004. "Effects of forest conversion to pasture on soil carbon content and dynamics in Brazilian Amazonia." *Agriculture, Ecosystems & Environment*, 103, no. 2: 365-373.

Fafchamps, M., and R. V. Hill. 2005. "Selling at the farmgate or traveling to market." *American Journal of Agricultural Economics*, 87, no. 3: 717-734.

Faminow, D. M. 1997. "Spatial economics of local demand for cattle products in Amazon development." *Agriculture, Ecosystems and Environment*, 62: 1-11.

Faminow, M., et al. 1999. "Smallholder risk, cattle, and deforestation in the Western Brazilian Amazon." *World Animal Review*, 93: 16-23.

Faminow, M. D. 1998. "*Cattle, deforestation and development in the Amazon: An economic, agronomic and environmental perspective"*, CAB International: New York.

Fearnside, P. M. 2002. "*Can pasture intensification discourage deforestation in the Amazon and Pantanal regions of Brazil*?", ed. C. H. Wood, and R. Porro. Gainesville, Florida, University of Florida press.

Fearnside, P. M., and R. I. Barbosa. 1998. "Soil carbon changes from conversion of forest to pasture in Brazilian Amazonia." *Forest Ecology and Management*, 108, no. 1-2: 147-166.

Fujisaka, S., et al. 1996. "Slash-and-burn agriculture, conversion to pasture, and deforestation in two Brazilian Amazon colonies." *Agriculture, Ecosystems & Environment*, 59, no. 1-2: 115-130.

Fujisaka, S., et al. 1998. "The effects of forest conversion on annual crops and pastures: Estimates of carbon emissions and plant species loss in a Brazilian Amazon colony." *Agriculture, Ecosystems & Environment*, 69, no. 1: 17-26.

Fujisaka, S., and D. White. 1998. "Pasture or permanent crops after slash-and-burn cultivation? Land-use choice in three Amazon colonies." *Agroforestry Systems*, 42, no. 1: 45-59.

Hecht, S. B. 1993. "The logic of livestock and deforestation in Amazonia." *Bioscience*, 43, no. 10: 687-696.

Hogan, D. J. "Sistemização das Informações Censitárias Sobre Migração: Estado de Rondônia - Dados demográficos." UNICAMP.

Hohnwald, S., et al. 2006. "Integrating cattle into the slash-and-burn cycle on smallholdings in the Eastern Amazon, using grass-capoeira or grass-legume pastures." *Agriculture, Ecosystems & Environment,* 117, no. 4: 266-276.

IBGE. "Contagem da População: Instituto Brasileiro de Geografia e Estatística."

IBGE. "Pesquisa Pecuária Municipal 2005: Instituto Brasileiro de Geografia e Estatística."

INPE. "Monitoring of the Brazilian Amazon Forest by Satellite 2002-2003."

Jones, D., et al. 1995. "Farming in Rondônia." *Resource and Energy Economics,* 17: 155-188.

Laurance, W. F., et al. 2001. "The future of the Brazilian Amazon." *Science,* 291:438-439.

Lee, D. R., P. J. Ferraro, and C. B. Barrett. 2001. "*Changing perspectives on agricultural intensification, economic development and the environment",* ed. D. R. Lee, and C. B. Barrett, CABI Publishing.

Leite, L. L., and P. A. Furley 1985. "*Land development in the Brazilian Amazon with particular reference to Rondônia and the Ouro Preto colonization project",* ed. J. Hemming, vol. 2, Manchester University Press, pp. 119-140.

Maddala, G. S. 1983. *Limited-dependent and Qualitative Variables in Econometrics*. Cambridge, UK: Cambridge University Press.

Margulis, S. 2003. "*Causes of deforestation of the Brazilian Amazon*". The World Bank.

Martine, G. 1990. *Rondônia and fate of small producers*, ed. D. Goodman, and A. Hall, St. Martins Press, New York.

Mattos, M. M., and C. Uhl. 1994. "Economic and ecological perspectives on ranching in the Eastern Amazon." *World Development*, 22: 145-158.

McGrath, D. A., et al. 2001. "Effects of land-use change on soil nutrient dynamics in Amazonia." *Ecosystems*, 4: 625-645.

Mertens, B., et al. 2002. "Crossing spatial analyses and livestock economics to understand deforestation processes in the Brazilian Amazon: The case of Sao Felix do Xingu in South Para." *Agricultural Economics*, 27: 269-294.

Muchagata, M., and K. Brown. 2003. "Cows, colonists and trees: rethinking cattle and environmental degradation in Brazilian Amazonia." *Agricultural Systems*, 76: 797-816.

Müller, M. M. L., et al. 2004. "The relationship between pasture degradation and soil properties in the Brazilian Amazon: a case study." *Agriculture, Ecosystems & Environment*, 103, no. 2: 279-288.

Murty, D., et al. 2002. "Does conversion of forest to agricultural land change soil carbon and nitrogen? A review of the literature. ." *Global Change Biology*, 8, no. 105-123.

Neill, C., et al. 2006. "Deforestation alters the hydraulic and biogeochemical characteristics of small lowland Amazonian streams." *Hydrological processes*, 20, no. 12: 2563-2580.

Nepstad, D. C., C. Uhl, and E. A. S. Serrão. "Recuperation of a degraded Amazonian landscape: Forest recovery and agricultural restoration." *Ambio* 20(1991): 248-255.

Nepstad, D. C., et al. 2001. "Road paving, fire regime feedbacks, and the future of Amazon forests." *Forest Ecology and Management*, 5524: 1-13.

Pacheco, P. 2005. "Populist and Capitalist Frontiers in the Amazon: Diverging Dynamics of Agrarian and Landuse Change." Doctoral dissertation, Doctoral dissertation, Clark University.

Pagiola, S., and S. Holden. 2001. *Farm household intensification decisions and the environment*. Tradeoffs or synergies? Agricultural intensification, economics development and the environment. Edited by C. B. Barrett, and D. R. Lee: CABI publishing, Wallingford, UK.

Pattanayak, S. K., and D. Butry. 2004. "Spatial complementarity of forests and farms: accounting for ecosystems services." *American Journal of Agricultural Economics*, 87, no. 4: 995–1008.

Pedlowski, M. A., and V. H. Dale. 1992. "*Land Use Practices in Ouro Preto do Oeste, Rondônia, Brazil*" Oak Ridge National Laboratory, Environmental Sciences Division, Publication No. 3850, ORNL/TM B 114770, Oak Ridge, TN.

Pendleton, L. H., and E. L. Howe. 2002. "Market integration, development, and smallholder forest clearance." *Land Economics*, 78, no. 1: 1-19.

Pfaff, A., et al. 2007. "Road investments, spatial spillovers, and deforestation in the Brazilian Amazon." *Journal of Regional Science*, 47, no. 1: 109-123.

Reardon, T., et al. 2001. *Sustainable versus unsustainable agricultural intensification in Africa: Focus on polict reforms and market conditions*. Tradeoffs or synergies? Agricultural intensification, economics development and the environment. Edited by D. R. Lee, and C. B. Barrett: CABI publishing, Wallingford, UK.

Reis, E. J., and S. Margulis. 1994. *An econometric model of Amazon deforestation.* The causes of tropical deforestation: the economic and statistical analysis of factors giving rise to the loss of tropical forests. Edited by K. Brown, and D. W. Pearce: University College London Press, London, U.K.

Romano, C. B. 2001. *Soil conservation and imperfect labor markets in el Salvador: an empirical application of a dynamic control model of farm production*, ed. N. Heerink, H. Van Keulen, and M. Kuiper. Heidelberg, Physica-Verlag.

Schneider, R., et al. 2001. "Sustainable Amazon: limitations and opportunities for rural development."

Seidl, F. A., S. J.d.S.V.d., and M. A.S. 2001. "Cattle ranching and deforestation in the Brazilian Pantanal." *Ecological Economics*, 36: 413-425.

Serrão, E. A. S., et al. 1979. Productivity of cultivated pastures on low fertility soils of the Amazon region of Brazil, ed. P. A. Sánchez, and T. E. Tergas. Cali, Colombia, Centro Internacional de Agricultura Tropical, Beef Program, pp. 195–225.

Serrão, E. A. S., and A. K. O. Homma. 1993. *Sustainable agriculture and the environment in the humid tropics*: National Research Council. National Academy Press, Washington, D.C.

Serrão, E. A. S., and J. Toledo. 1990. *The search for sustainability in Amazonian pastures*. Alternatives to Deforestation: Steps towards sustainable use of the Amazon rain forest. Edited by A. B. Anderson. New York: Columbia University Press.

Sexton, R. J. 1990. "Imperfect competition in agricultural markets and the role of cooperatives: A spatial analysis." *American Journal of Agricultural Economics,* 72: 709-20.

Shilpi, F., and D. Umali-Deininger. 2007. "Where to sell? Market facilities and agricultural marketing." *World Bank Policy Research Working Paper* 4455.

Singh, I., L. Squire, and J. Strauss. 1986. *Agricultural Household Models: Extensions, Applications, and Policy*: Baltimore: The John Hopkins University Press.

Takaski, Y. 2007. "Dynamic household models of forest clearing under distinct land and labor market institutions: can agricultural policies reduce tropical deforestation?" *Environment and Development Economics,* 12: 423-443.

Tinker, P. B., J. S. I. Ingram, and S. Struwe. 1996. "Effects of slash-and-burn agriculture and deforestation on climate change." *Agriculture, Ecosystems & Environment,* 58, no. 1: 13-22.

Torras, M. 2000. "The total economic value of Amazonian deforestation, 1978–1993." *Ecological Economics,* 33, no. 2: 283-297.

Vosti, S., C. L. Carpenter, and A. Witcover 2001. Intensified small-scale livestock systems in the Western Brazilian Amazon, ed. A. Angelsen, and D. Kaimowitz, CIFOR. CABI publishing.

Vosti, S., J. Witcover, and C. L. Carpentier. 2001. "*Agricultural intensification by small-holders in the Western Brazilian Amazon - from deforestation to sustainable land use.*" International Food Policy Research Institute IFPRI, Washington DC.

Vosti, S. A., and T. Reardon. *Sustainability, growth, and poverty alleviation: a policy and agroecological perspective.*: Johns Hopkins University Press, Baltimore., 1997.

Vosti, S. A., J. Witcover, and C. L. Carpentier. 2001. "*Agricultural intensification by smallholders in the western Brazilian Amazon: from deforestation to sustainable land use*." International Food Policy Research Institute, Environment and Production Technology Division, Washington, DC.

Vosti, S. A., et al. 2001. *Intensifying small-scale agriculture in the Western Brazilian Amazon: Issues, implications and implementation*. Tradeoffs or synergies? Agricultural intensification, economics development and the environment. Edited by C. B. Barrett, and D. R. Lee: CABI publishing, Wallingford, UK.

Walker, R., E. Moran, and L. Anselin. 2000. "Deforestation and cattle ranching in the Brazilian Amazon: External capital and household processes." *World Development,* 28: 683-699.

Walker, R., et al. 2002. "Land-use and land-cover change in forest frontiers: The role of household life cycles." *International Regional Science Review,* 25: 169-199.

White, D., et al. 2001. "*Will intensifying pasture management in Latin America protect forests - or is it the other way around?*", ed. A. Angelsen, and D. Kaimowitz, CAB International, Wallingford, UK.

World Bank Report. 2006. "*A decade of action in transport: An evaluation of World Bank assistance to the transport sector, 1995-2005*." The World Bank.

More wealth but poor health? Examining the local health impacts of iron ore mining in India

Auty, R. 2006. “Mining enclave to economic catalysts: Large mineral projects in developing countries.” *Brown Journal of World Affairs,* Vol. XIII, Issue 1, Fall/Winter.

Bandiera, O., and I. Rasul. "Social Networks and Technology Adoption in Northern Moz ambique." *The Economic Journal*, 116(2006): 869-902.

Barat, L. M. 2006. “Four malaria success stories: How malaria burden was successfully reduced in Brazsil, Eritrea, India and Vietnam.” *American Journal of Tropical Medicine and Hygiene*, 74(1), 12-16.

Bravo-Ortega, C. and De Gregorio, J. 2005. “The relative richness of the poor? natural resources, human capital, and economic growth.” No 3484, *Policy Research Working Paper Series*, The World Bank.

Bridge, G. 2004. “Contested terrain: Mining and the environment.” *Annual Review of Environmental Resources*. 29, 205-29.

Bruce, N., R. Perez-Padilla and R. Albalak, 2000. “Indoor air pollution in developing countries: a major environmental and public health challenge.” World Health Organization. 78, 1097-1092.

Bulte, E.H, R. Damania and R. Deacon. 2005. “Resource intensity, institutions and development.” *World Development,* Volume 33 (7) 1029-1044.

Cameron, A. C. and Trivedi, P. K. 1986. “Econometric models based on count data: comparison and application of some estimators.” *Journal of applied Econometrics*, 1, 29-53.

Cameron, A. C. and Trivedi, P. K. 1998. “Regression analysis of count data.” Cambridge University Press.

Chaulya, S. K. 2004. “Spatial and temporal variations of SPM, RPM, SO2 and NOx concentrations in an opencast coal mining area.” *Journal of Environmental Monitoring*, Vol. 6, 134-142.

Dasgupta, S., Huq, M., Khaliquzzaman. M. and Wheeler, D. 2007. “Improving indoor air quality for poor families: A controlled experiment in Bangladesh.” *World Bank Policy Research Working Paper* 4422.

Dudka, S. and Adriano, D. C. 1997. “Environmental impacts of metal ore mining and processing : A review.” *Journal of environmental quality*, Vol. 26(3), 590-602.

Duflo, E., Greenstone, M. and Hanna, R. 2007. “Indoor air pollution, health and economic well-being.” Working paper, Poverty Action Lab.

Dickinson, K. and Pattanayak, S. K. 2008. “Open sky latrines: Do social interactions influence decisions to use toilets?” Working paper.

Ethridge, D. E. 2004. “*Research methodology in applied economics: organizing, planning and conducting economic research.*” Iowa State University Press.

Freudenburg, W. R. and Wilson, L. J. 2002. “Mining the data: Analyzing the economic implications of mining for nonmetropolitan regions.” *Sociological Inquiry*, 72(4), 549-75.

Geist, H.J. and Lambin, E. F. 2002. “Proximate causes and underlying driving forces of tropical deforestation.” *Bioscience*, Vol 52, No 2, 143-150.

Ghose, M. K. and Majee, S. R. 2000. “Assessment of the impact on the air environment due to opencast coal mining: an Indian case study.” *Atmospheric Environment*, 34, 2791-2796.

Hamilton, K., Ruta, G., Tajibaeva, L. 2005. “Capital accumulation and resources depletion - a Hartwick rule counterfactual.” No 3480, *Policy Research Working Paper Series*, The World Bank.

Hancock, G. 2002. “*Sharing the Risks and Rewards of Mining*.” World Bank Mining Sector Technical Assistance Project. http://www.wmmf.org/historical/2002docs/miningpeople/Mining_People_Hancock.pdf Accessed on March 2, 2008.

Hartwick, J., 1977. “Intergenerational equity and investing rent from renewable resources.” *American Economic Review*, 67 (5), 972–976.

Hedlund, U., Järvholm, B., Lundbäck, b. 2006. “Persistence of respiratory symptoms in ex-underground iron ore miners.” *Occupational Medicine*, 56, 380-385.

Hilson, G. 2002. “Small scale mining and its socio-economic impact in developing countries.” *Natural Resources Forum*, 26, 3-13.

International Labour Office. 1997. “*Encyclopedia of Occupational Health and Safety*.” 4th edn. Geneva: International Labour Office.

Jalajakshi, C. K. 2005. “Improved cook stove dissemination: Experience from Andhra Pradesh, India.” *Boiling Point*, No 51 2005.

Joyce, S. 1998. “Major Issues in Miner Health.”*Environmental Health Perspectives*, Vol. 106, No. 11, A538-A543.

Krishnaswamy, J., Bunyan, M., Mehta, V. K., Jain, N. and Karanth, U. K. 2006. "Impact of iron ore mining on suspended sediment response in a tropical catchment in Kudremukh, Western Ghats, India." *Forest Ecology and Management*, Volume 224, Issues 1-2, 187-198.

Kumar, A., Valecha, N., Jain, T., Dash, A. P. 2007. "Burden of Malaria in India: Retrospective and Prospective View." *The American Journal of Tropical Medicine and Hygiene*, 77(6_Suppl), 69-78.

Lambert, d. 1992. "Zero-inflated Poisson regression with an application to defects in manufacturing." *Technometrics*, 34, 1-14.

Long, J. S. and Freese, J. 2006. "*Regression models for categorical dependent variables using Stata*." 2nd edition. Stata Press.

Matthews, E. 2000. "*Undying Flame: The Continuing Demand for Wood as Fuel*." Excerpted from Pilot Analysis of Global Ecosystems: Forest Ecosystems. EarthTrends publication.

Meltzer, M. I. et al. 2003. "The household-level economics of using Permethrin-treated bed nets to prevent malaria in children less than five years of age." *American Journal of Tropical Medicine and Hygiene*, 68(4 suppl), 149-160.

Misra, S. P. et al. 1999. "Malaria control: bed nets or spraying? Spray versus treated nets using deltamethrin – a community randomized trial in India." *Transactions of the Royal Society of Tropical Medicine and Hygiene*, 93, 456-457.

NCAER. 1993. "*Evaluation survey of National Program on Improved Chulha*." National Council for Applied Economic Research (NCAER), New Delhi.

Nuwaha, F. 2001. "Factors influencing the use of bed nets in Mbarara municipality of Uganda." *American Journal of Tropical Medicine and Hygiene*, 65 (6), 877-882.

Patz, J.A. et al. 2004. "Unhealthy Landscapes: Policy recommendations on land use change and infectious disease." *Environmental Health Perspectives*, Vol. 112, No. 10, 1092-1098.

Peters, C. M., A. H. Gentry, and R. O. Mendelsohn. 1989. "Valuation of an Amazonian rainforest." *Nature*, 339:655–656.

Pless Mulloli, T., D. Howel, et al. 2000. "Living near opencast coal mining sites and children's respiratory health." *Occupational and Environmental Medicine*, 57(3): 145-51.

Rasmussen, R.O. and N.E. Koro leva, ed. 2003. "*Social and Environmental Impacts in the North*."

Ripley, E.A., R.E. Redman, and A.A. Crowder. 1996. "*Environmental Effects of Mining.*"

Ross, M. H. and Murray, J. 2004. "Occupational respiratory disease in mining." *Occupational Medicine*, 54, 304-310.

Ross, Michael L. 2001. "*Extractive Sectors and the Poor: An Oxfam America report.*" Boston, MA: Oxfam America. (Available at http://www.oxfamamerica.org/art545.html). Accessed on March 12, 2008.

Sachs, J.D and A.M. Warner, 1997. "*Natural Resource Abundance and Economic Growth.*" NBER Working Paper Series, WP 5398, Cambridge: National Bureau of Economic Research.

Sachs, J.D and A.M. Warner, 2001. "The Curse of Natural Resources." *European Economic Review*, 45: 827-838.

Saxena, N.C., G. Singh, and R. Gosh. 2002. "*Environmental Management in Mining Areas*."

Sharma, S. K. et al. 2006. "Effectiveness of mosquito nets treated with a tablet formulation of Deltamethrin for malaria control in a hyperendemic tribal area of Sundargarh district, Orissa, India." *Journal of the American Mosquito Control Association*, 22(1), 111-118.

Sinha, S., Bhattacharya, R. N., Banerjee, R. 2007. "Surface iron ore mining in eastern India and local level sustainability." *Resources Policy*, Volume 32, Issues 1-2, 57-68.

Singh. G. and Sharma, P. K. 1992. "A study of spatial distribution of air pollutants in some coal mining areas of Raniganj coalfield, India." *Environment International*, Volume 18, Issue 2, 191-200.

Smith, K.R., J. Zhang, R. Uma, V.V.N. Kishore and M.A.K. Khalil, 2000: "Greenhouse implications of household fuels: an analysis for India." *Annual Review of Energy and Environment*, 25, 741-763.

Stephens, C. and Ahern, M. 2001. "*Worker and community health impacts related to mining operations internationally: A rapid review of the literature*." Report prepared for the Mining, Minerals and Sustainable Development project. International Institute for Environment and Development (IIED).

Tata Energy Research Institute (TERI). 2001. "*Overview of mining and mineral industry in India*." Report commissioned by the Mining, Minerals and Sustainable Development project. International Institute for Environment and Development (IIED).

Takken, W., Vilarinhos, P., Schneider, P., Santos, F. dos .2003. "*Effects of environmental change on malaria in the Amazon region of Brazil*." In Environmental change and malaria risk: global and local implications: Proceedings of the Frontis workshop on Environmental Change and Malaria Risk: Global and Local Implications, Wageningen, The Netherlands 12-14 November; Wageningen UR Frontis series Vol. 9, 113 - 123.

Wallmo, K, and Jacobson, S. K. "A social and environmental evaluation of fuel-efficient cook-stoves and conservation in Uganda." *Environmental Conservation*, 25(2): 99–108.

Weber-Fahr, M. 2002. "*Treasure or Trouble?: Mining in Developing Countries*." The World Bank and International Finance Corporation report.

Webster, D. 2001. "Malaria kills one child every 30 seconds." *Journal of Public Health Policy*, 22(1), 23-33.

WHO report. 2006. “Fuel for life: Household energy and health.”

World Bank Report 2007. “*Towards sustainable mineral–intensive growth in Orissa - managing environmental and social impacts*.” Environment Unit, Sustainable Development Department, South Asia Region. Report No. 39878-IN.

World Resources Institute 2004. “*Mining and Critical Ecosystems: Mapping the Risks*.” Washington, DC: World Resources Institute.

Yadav, R. S., Ghosh, S. K., Chand, S. K., Kumar, A. 1991. “Prevalence of malaria and economic loss in two major iron ore mines in Sundargarh District, Orissa.” Indian *Journal of Malariology*, Vol. 28(2), 105-113.

Yadav, R. S., Sampath, R. R. and Sharma, V. P. 2001. “Deltamethrin trated bed nets for control of malaria transmitted by *Anopheles culcifacies* in India.” *Journal of Medical Entolmology*, 38(5), 613-622.

Yasuoka, J. and Levins, R. 2007. “Impact of deforestation and agricultural development on Anopheline ecology and malaria epidemiology.” *American Journal of Tropical Medicine and Hygiene*, 76(3), 450-60.

GIS APPENDIX

This section outlines the various spatial tools and methods that I have used to construct variables and perform statistical analyses. I provide brief synopses of the two empirical chapters in my dissertation to motivate and put in context the need for spatially explicit variables. The dataset I am using consists of the following spatial information. Different combinations of these spatial elements have been processed in ArcGIS 9.2 and GeoDa[42] to construct variables and perform econometric analyses.

Spatial features of the dataset:

(1) All the roads (paved and unpaved secondary roads) in the study area have been GPS-ed.
(2) The land parcels are all digitized from original survey maps that were used at the time of allotment of parcels.
(3) GPS of the location of all the farmers who were surveyed.
(4) GPS for main town of Ouro Preto and other municipal towns.
(5) GPS for location of all milk plants that collect milk from the study area.
(6) GIS of distribution of soil quality for the entire study area.
(7) A DEM layer for the entire study area that provides information on terrain.
(8) Classified Landsat imagery for the study area for 1990, 1996, 2000 and 2005. Images used in supervised classification were acquired roughly over the same time period to minimize bias that arises due to response of local vegetation to climatic factors like temperature and rainfall.

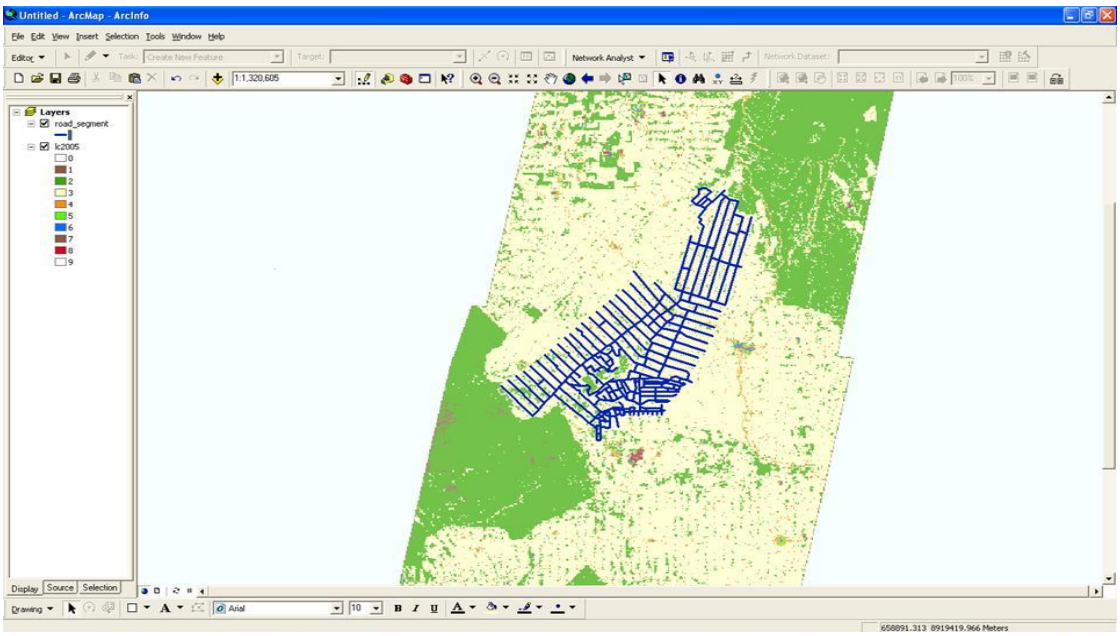
Processing spatial data:

[42] GeoDa is a free software to conduct spatial econometrics and has been developed by a team led by Luc Anselin (2003). The software is downloadable from https://www.geoda.uiuc.edu/

In this section, I describe the methodology used to process the spatial information and the various tools that were used to construct variables utilizing this spatial information. The variables described below have been used throughout the dissertation, while those calculated for specific chapters are described after the description of the respective chapter.

- *Landcover data*: The digitized parcel layer and classified temporal images[43] were combined to calculate the areas in pasture, forests and other categories using a combination of tools in ArcGIS 9.2. First, there were two Landsat tiles (Ji-Paraná and Luiza) used to cover the entire study area. The processed tiles needed to be merged together. I used the Data Management Tools > Raster > Mosaic functions to blend the two images together. Fro the area that overlapped between the two tiles, I chose to keep the pixel value that was higher among the overlapping pixels. The mosaic was in GRID format that was converted to a Polygon Feature Class using the Conversion Tools > Raster to Polygon functions. To extract the landcover data within each parcel, I used the land cover data that was converted to Feature Class and the shapefile with the digitized parcel boundaries. I used the Analysis Tools > Overlay > Intersect functions to obtain a list of polygons by each land cover class for each land parcel. I then used a short SAS code to aggregate the polygons by landcover class and then by individual parcels to obtain the total area in each land cover class in each parcel. The landcover classes identified in the classified images were: primary forest, secondary forest, pasture, green pasture, burnt pasture, water, urban/soils and rock/savanna. This process was repeated for the images corresponding to 1990, 1996, 2000 and 2005.

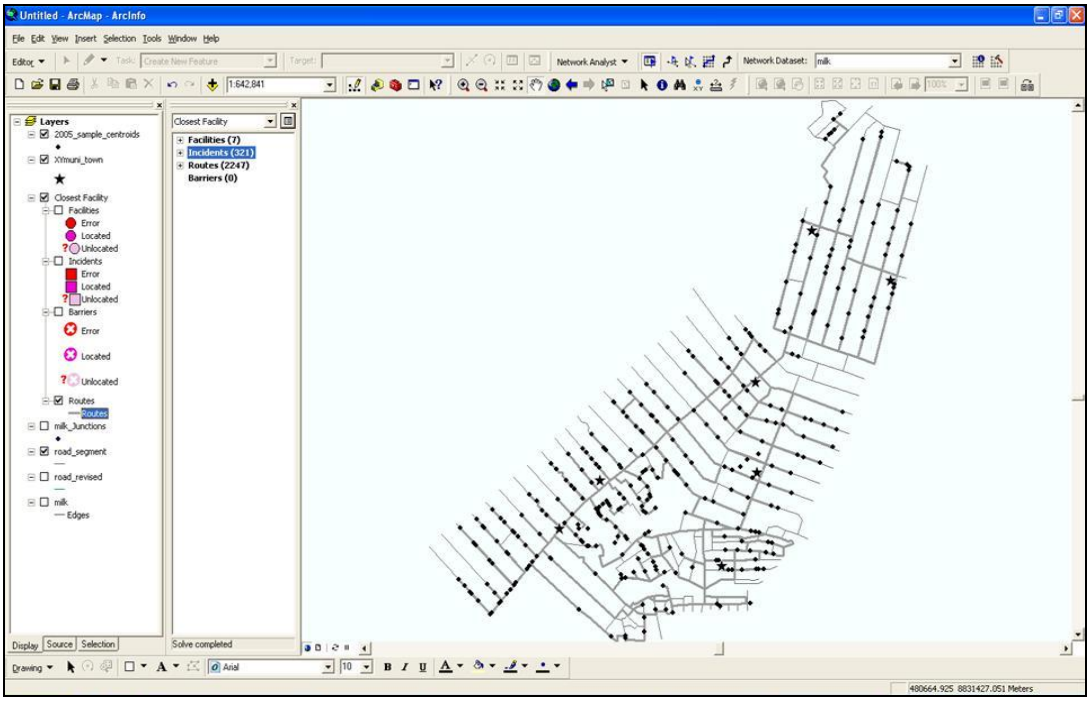
[43] The classified landcover images were obtained from Dr Dar Roberts at University of California, Santa Barbara.



> *Distance to towns*: Utilizing the spatial data on roads and location of farmers who were included in the survey, distances to nearest city and municipal town is calculated using the Network Analyst tool in ArcGis 9.2. In the agriculture and development economics literature, distance to markets and access to infrastructure are important explanatory factors of individual behavior. E.g., transportation costs are an important component of input and output prices based on which private land use decisions are made. Access to schools and medical facilities affect education and health outcomes that determine human development. Explicit information on roads and location of farmers with respect to the road allow me to calculate farmer-specific distances to the towns and markets.

I use the Network Analyst tool, where 'Incidents' are defined as centroids of farmer parcels and 'Facilities' are defined as the municipal towns to calculate road-based distances. I manually moved the centroids of the land parcels to the front of the parcel

in order for them to coincide with the road polylines. This procedure provides road distances for each parcel to every town in the study area, from which distance to nearest municipal town and Ouro Preto do Oeste town were obtained. In order to calculate the Euclidean distance, I used the Analysis Tools > Proximity > Near functions.



> *Biophysical variables*: The digitized land parcel layer was overlaid on the soil classification shapefile and the DEM layer to extract soil quality and terrain information specific to each land parcel. I used the Analysis Tools > Overlay > Intersect functions to obtain these information specific to each parcel. In cases where

there were multiple soil classes present within a single land parcel, the class with the maximum area was chosen. For elevation data, I calculated the following variables after performing the overlay function – maximum slope on the lot, average slope on the lot, dummy variables if the parcel had a slope gradient of more than 20, 30 and 50 respectively.

> *Transition matrices for landcover*: In order to obtain landscape-level changes in land cover, I calculated transition matrices using the landcover information for the four survey years. I used the Spatial Analyst Tool > Zonal > Tabulate Area functions for the landcover mosaics for each survey year

% change of 1990 landcover classes into other categories in 2005										
		2005								
		Rock/ Savanna	Primary forest	Pasture	Green pasture	Secondary forest	Water	Urban/ Bare soil	Burn pasture	
1990	Rock/Savanna	100	0	0	0	0	0	0	0	100
	Primary forest	0	42.62	55.72	0.04	1.35	0.06	0.02	0.19	100
	Pasture	0	2.25	96.62	0.05	0.54	0.09	0.17	0.28	100
	Green pasture	0	2.63	95.69	0.29	0.76	0.36	0.05	0.23	100
	Secondary forest	0	12.56	81.93	0.35	4.95	0.05	0.03	0.13	100
	Water	0	26.33	10.32	0.00	0.06	61.64	0.00	1.64	100
	Urban/Bare soil	0	0.32	67.50	0.05	0.06	0.29	24.47	7.30	100
	Burn	0	5.33	88.97	0.01	0.15	1.37	1.18	2.99	100
		100	92.04	496.76	0.79	7.86	63.87	25.92	12.77	

> *Landscape metrics*: The motivation behind calculating landscape metrics was to ascertain the landscape configurations as an outcome of human processes. Though not

directly part of the dissertation, I will like to expand on this work to examine the feedback how land use decisions of farmers create particular landscape configurations, and in turn what impact these configurations on landscape productivity. The Fragstats software (McGarigal, 1995) is the most commonly used tool for calculating landscape metrics. The primary problem to use Fragstats was that I wanted to calculate fragmentation metrics at the parcel level, rather than the landscape level. Fragstats would only read a shapefile with all the parcels included, and calculate landscape level metrics rather than individual parcel level. I used an Arc Script[44] that creates a batch file for all the individual polygons in a shapefile (individual parcels in this case) and calculates required landscape metrics at the individual parcel level using Fragstats.

Chapter 1: In this chapter, I am trying to examine how information networks of individual farmers affect their land use choices in the Amazon frontier. In remote regions characterized by weak institutions and inadequate infrastructure, farmers face information constraints regarding alternative forms of farming technology. The importance of collective learning in these areas, where individuals share and learn from 'neighbors', have often been cited in the literature and provide the rationale for promoting farmer cooperatives and strengthening farm extension activities. In the study area of Ouro Preto do Oeste in Rondônia, Brazil, there are two primary sources where farmers can share and obtain information regarding alternate forms of land use: (a) through farmer associations which were established to help diversified agricultural practices; (b) from other farmers living close to one's land parcel as transportation infrastructure is poorly developed and mobility of farmers are extremely restricted. This characterization of information sources gives rise two alternative definitions of 'neighborhood' that farmers may belong to – 'social' and 'spatial'. The 'social' neighborhood for a farmer is defined as all farmers

[44] Downloaded from http://arcscripts.esri.com/details.asp?dbid=13995 on 20 September, 2007

who belong to the same farmer association. The 'spatial' neighborhood for an individual farmer is defined as all farmers who live on the same road based on the location of the farmer. Evidence of influence among 'social' neighbors have important policy implications, as it provides reasons to promote these farmer associations in disseminating technological information and marketing support to encourage particular types of land use that are economically profitable and ecologically sound. Empirical investigation of such 'social' influence is complicated by the fact that observed commonalities in land use practices among farmers belonging to the same association can actually be an outcome of influence from 'spatial' neighbors rather than 'social'. I control for such spatial influence to test the significance of 'social' neighbors in the econometric analyses.

Model:

I have developed spatial econometric models to assess the impact of neighborhood influence on individual land use decisions. The underlying rationale behind traditional spatial econometric models is that individual outcomes are correlated across space, with the influence of agents closer in space being stronger than those further away. This follows from Tobler's first law of geography which says that "everything is related to everything else, but near things are more related than distant things". Econometrically, such interconnectedness is captured through construction of a weights matrix, where each cell [i, j] in the matrix captures the hypothesized relation between agents i and j.
This relationship is often represented as

(i) *binary*, with [i, j] = 1 if agents i and j share common boundaries (commonly used in studies where the unit of observation are administrative boundaries like districts or states that are contiguous) and [i, j] = 0 otherwise.

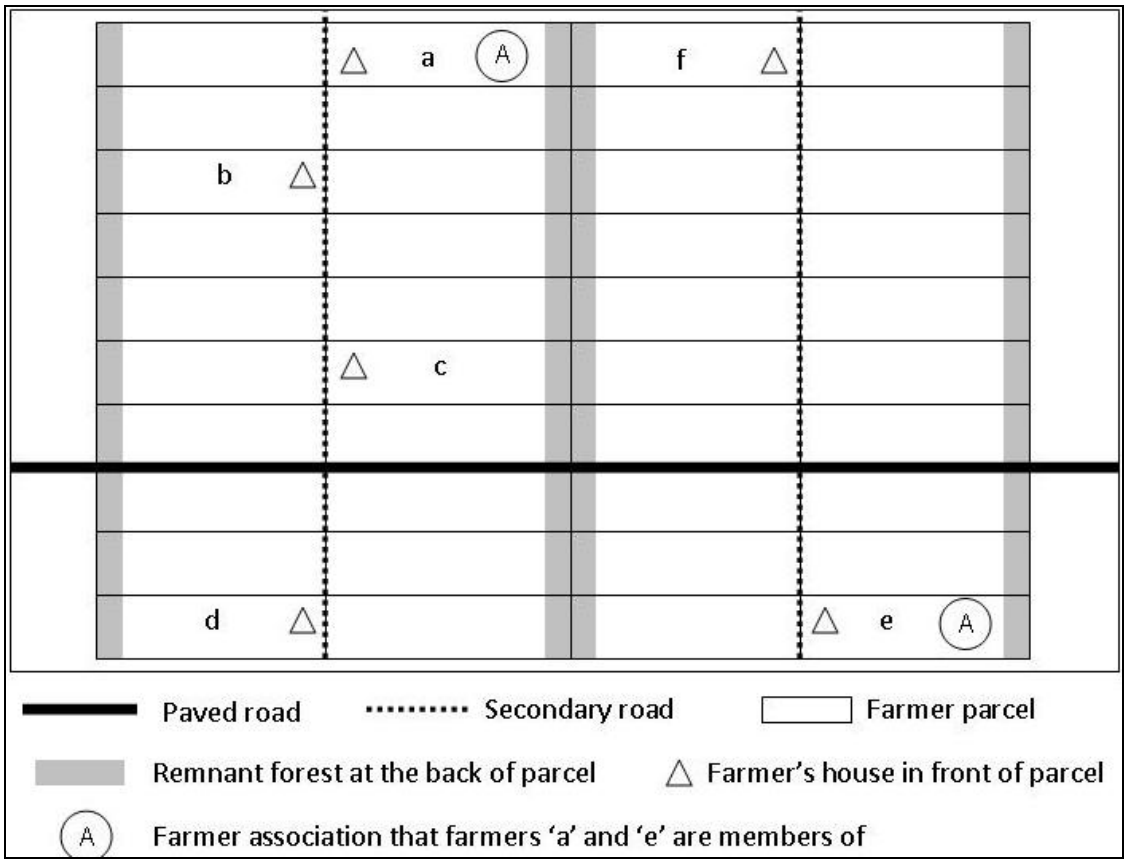
(ii) *inverse-distance* based, with [i, j] = 1/d if Euclidean distance between agents i and j is measured in d units.

(iii) *nearest-neighbor*, which is a hybrid of the binary weights and distance based matrices. Having specified an arbitrary number of neighbors, agents i and j are

hypothesized to be neighbors if they are close enough. For example, in the case of k nearest neighbors, cell [i, j] = 1 if agent j happens to be one of the k nearest neighbors for agent i.

In my analyses, I have used two different weights matrices to capture the 'social' and 'spatial' neighborhoods for individual farmers.
(i) *Social weights* matrix is defined as cell [i, j] = 1 if agents i and j belong to the same farmer association (A), and [i, j] = 0 if agents i and j are not members in the same association.
(ii) Spatial weights matrix is defined as cell [i, j] = 1 if agents i and j live on the same road, and [i, j] = 0 if they do not. Unlike the construction of the traditional spatial weights matrix, where all agents are related to each other based on inverse distances, the spatial configuration of farmer parcels in the study area require a different characterization of spatial relationships.

The schematic in Figure 1 illustrates the spatial arrangement of land parcels in the study area. The settlement pattern is grid-shaped – unpaved secondary roads (*linhas*) are connected to a principal paved road. Parcels (mostly 100 hectares in area – 500 m x 2 km) are distributed on either side of the secondary roads that were randomly assigned to farmers in the course of the land settlement process. Upon settlement, the farmers start clearing forest from the front of the lot, where there houses are constructed. As a result, over time, the extensive margin of forest is pushed towards the back of the lot



Schematic indicating the spatial arrangement of land parcels and the rationale behind the construction of the weights matrices

(this process gives rise to the fishbone pattern of deforestation on the landscape). The length of the lots (2km) and the forest at the back of the lot limit the chances of interaction among farmers (e.g., farmers a and f) with those living on the parallel secondary road. Thus, farmers 'a', 'b', 'c' and 'd' are hypothesized to be 'spatial' neighbors as they use the same secondary road to get to the paved road. Note that construction of spatial weights matrix defined by nearest neighbor based method of using Euclidean distances will include farmer 'f' in the neighborhood of farmer 'a', though my experience from fieldwork suggest that the spatial configuration of the settlement imposes physical constraints on interactions between farmers 'a' and 'f' as described above. Thus, 'spatial' weights matrices defined on the basis of residence on the same

secondary road is preferred, but nearest neighbor matrices are also developed to compare results using both.

The 'social' weights matrix according to the schematic (Figure 1) will identify farmers 'a' and 'e' as neighbors, as both of them report to be participating in the same farmer association.

Having constructed these alternative weights matrix, the econometric model is analogous to a spatial autoregressive model as developed by Anselin (1988). It takes the following form:

$$\begin{aligned} Y &= \rho W_s Y + \lambda X + \mu \\ \mu &= \eta W_p \mu + \varphi \\ \varphi &\sim N(0, \sigma^2 I) \end{aligned} \qquad (1)$$

Y	: area in particular land use devoted by a farmer
X	: vector of exogenous characteristics of farmer i that influence his land use decision
$W_s Y$	: average area in particular land use devoted by other members in the same farmer association
W_s	: weights matrix based on association membership
W_p	: weights matrix based on physical proximity

The coefficient of interest is the spatial autoregressive coefficient ρ that will indicate existence of interaction effects between farmers belonging to the same farmer association (captured through W_s). If a farmer does not belong to a farmer association, then it is only his exogenous characteristics that explain his land use decision. A positive and significant ρ indicates that individual land use outcome is influenced by decisions made by other members in the same farmer association. As mentioned before, the common outcomes among agents could be a result of influence from neighbors living on the same road. If the latter is the actual source of influence and is unaccounted in the regression, then the social influence capture through ρ will overestimate the influence of

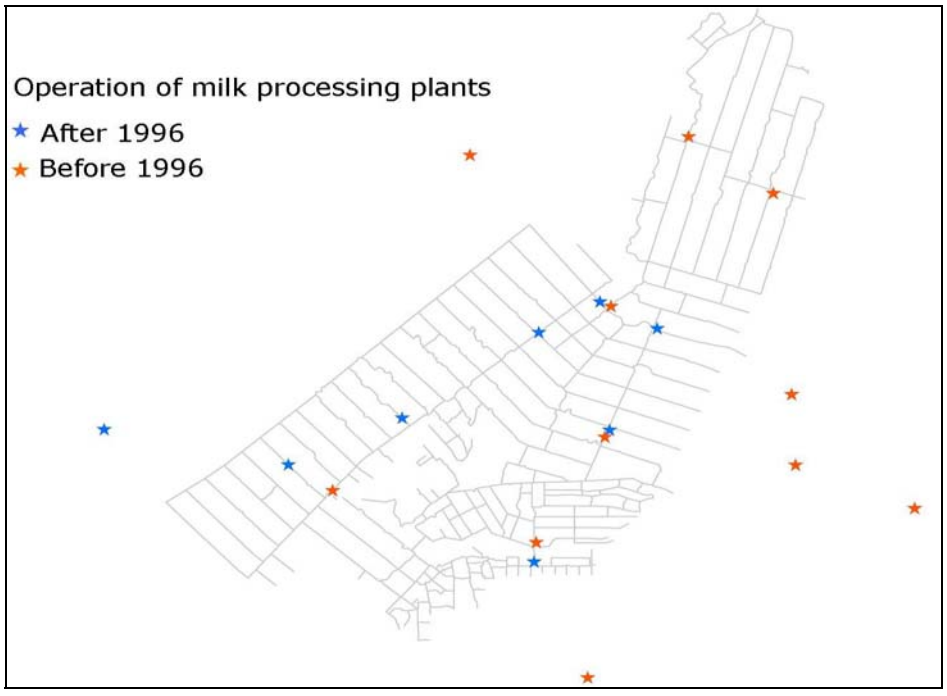
'social' neighbors. The bias that could arise from 'spatial' influence is captured by the W_p matrix in the error equation.

Variables:

- *Weights matrices*: The 5 nearest neighbor based weights matrix is constructed using GeoDa. While GeoDa produces weights matrices with a .gwt file extension, I converted those matrices in SAS into formats that could be used in regression analyses using R and Stata. The weights matrices based on location of farmers on the same secondary road were calculated manually by translating the GIS information into excel spreadsheet and using PROC IML in SAS to convert the data spreadsheet into matrix format.
- *Average distance of farmers belonging to same association*: Using Network Analyst, I calculate road distances between all farmers in the sample. In the survey, farmers also report the associations that they are members of. Combining these two pieces of information, I calculated the average distance of members belonging to the same association for each farmer. This variable is used in the regression to explain participation of farmers in associations. If average distance to other association members is negative and significant in explaining participation of an individual in the association, then it will point to the fact that membership in association is spatially clustered.

Chapter 2: In this chapter, I investigate if the increase in the number of milk processing plants in the region has provided incentives to farmers to intensify their pasture management. The common land use strategy among small farmers in the Amazon frontier has been to clear forest to grow a mix of annual and perennial crops. Over time, the cleared land is converted to pasture and it becomes the dominant land use. This land use strategy has faced widespread criticism and is blamed for much of the deforestation of the

Amazon attributed to small farmers. Besides land clearing for speculative reasons and insecure property rights, farmers tend to increase cattle herd and production of milk and beef by extensifying their pastures. This strategy not only results in further clearing of forests, but lack of attention to maintain or increase soil productivity renders these cleared areas unproductive after a few years of use. Financial constraints are cited as one of the reasons behind the lack on investments on part of the farmers in intensification of the pasture. Over the last decade in the study region, there has been significant increase in the number of milk processing plants. The local milk industry has transitioned from being monopolistic to competitive. As suppliers of milk, small farmers have been able to command a higher price for sale of milk. With the prospective increase in revenue from milk, I investigate in this chapter if this has encouraged farmers to re-invest part of the profits to more intensive pasture management.

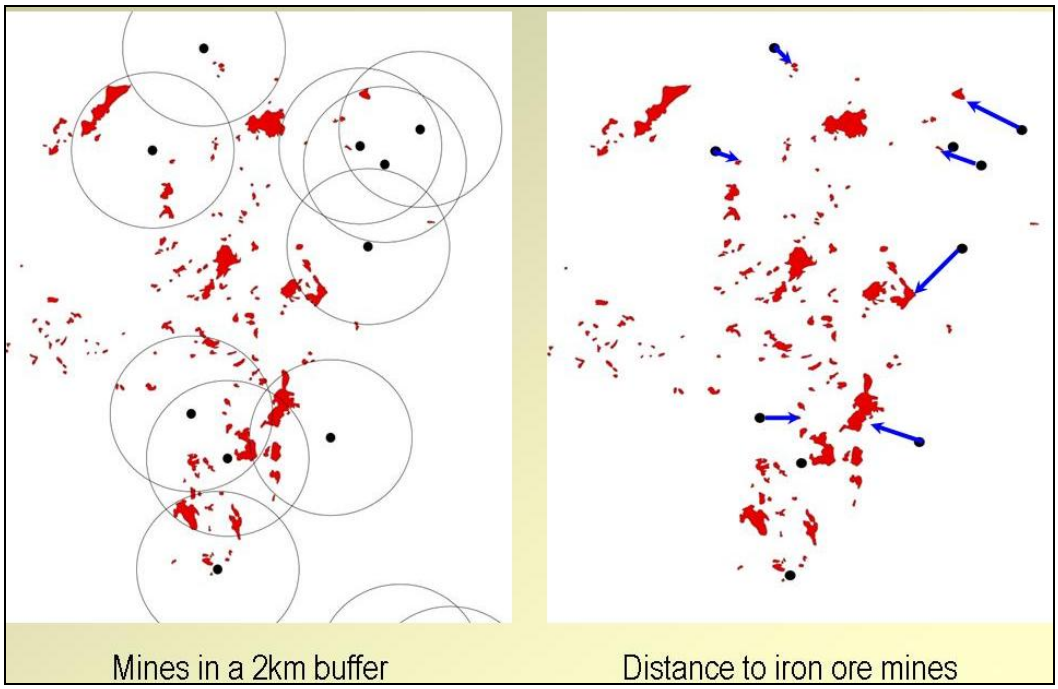


Map indicating the increase of milk processing plants from 1996 to 2005

Variables:

- *Distance of farmers to milk processing plants*: An indicator of increased competition among milk plants is that the average number of plants collecting milk from farmers has increased from 1.4 in 1996 to 3.1 in 2005. With more milk plants being established within the study area, the distance between farmer's parcel and the milk plant has diminished over time. This has repercussions on the transportation cost of milk, and lower costs could translate into higher farmgate prices for milk. I use Network Analyst to calculate the distance between the farmer parcels to each milk plant in the region. This data is combined with information on year of operation for each milk plant to calculate measures of market access for farmers in each of the 3 survey years.
- *Number of milk plants within a buffer area*: As another measure of increased competition in the local milk industry, I calculate the number of plant that fall within a 2, 5 and 10 km buffer for each farmer. This number increases over the survey years and indicates that each farmer had a greater option of selling milk to more plants. I use the Analyst Tools > Proximity > Buffer functions to calculate buffers around the centroids for each parcel. Then the shapefile containing the locations of each milk plant is used in combination with the buffer layers to calculate the number of plants falling inside each buffer. For the second part of the calculations, I use the Analyst Tools > Overlay > Intersect functions.

Chapter 3: utilizing the Gis information on location of villages and iron ore mines, alternative definitions of mine exposure are constructed. These measures are based on either Euclidean distance, or number of mines in a 2 km buffer around each village.


Mines in a 2km buffer
Distance to iron ore mines

Summary and questionnaire for fieldwork supported by Doctoral Dissertation Improvement Grant from the National Science Foundation in 2006

Objectives:

Understanding factors that influence land use choices of farmers in the Amazon frontier could better inform two policy goals – control deforestation and increase welfare of the rural population in the frontier. Typically, migrant farmers deforest the land allotted to them and predominantly use the cleared land for agriculture and/or pasture. This land use choice depends, among other factors, on expansion in local market opportunities of farm produce as well as on the availability of technological information regarding land use practices. This project is developed to empirically examine how these land use choices evolve over time.

Specifically, this project aims to examine:

(1) how expansion of the local market for milk and beef has affected pasture management decisions

(2) if increase in number of farmer associations have helped in diffusion of information regarding agricultural technology

Research summary:

(1) Government policy has facilitated integration of the Amazon into national and international markets, encouraging the establishment of milk and beef processing plants. Cattle ranching have become the preferred land use for many small farmers because of high relative profits from the sale of milk and beef. But extensive deforestation resulting from increase in land for pasture (extensification) continues to fuel debate over the sustainability and environmental cost of pasture. While an increase in the number of processing plants increases farmers' options as suppliers of milk and beef, the impact of processing plants on land use decisions of farmers is less obvious. This project examines

whether increase in market opportunities have led farmers to adopt more intensive pastoral systems or convert more forest to pastures.

To accomplish this, following tasks were undertaken during fieldwork:

(i) Interviews were conducted with all the nineteen milk processing plants that collect milk from the study area. Similar interviews were conducted with three beef production facilities in the region. Questionnaires were designed to obtain quantitative and qualitative information on:

- how capacity of each plant and infrastructure has changed since inception
- how area of milk collection has changed over the years and across season
- profile of farmers who sell milk to the plant
- regional/national markets that the milk processing plants are linked to along the supply chain
- opinion of managers on how livestock and pasture management strategies of farmers have changed as the dairy industry has expanded in the region
- GPS data on location of these milk plants and beef producing facilities

(ii) Interviews were conducted with all the farmers living on the same parcel since 1996, who were interviewed as part of previous NSF funded projects in the study area (NSF-SES-0452852, NSF-SES-0076549). This provides the rare opportunity to study the dynamic nature of land use choices made by households in response to expanding market opportunities.

- history of livestock ownership, beef and milk production
- choices driving farmers to chose different milk processing plants to sell milk to since 1996

- specific investment undertaken by farmers with respect to livestock and pasture productivity
- factors that influence farmers' livestock management strategies

This data is then assembled in a GIS that includes location of farmer parcels and the processing facilities. This allows spatially explicit analyses of combining household interview data with land cover information derived from satellite imagery and plant locations to assess how land use choices were affected by expansion of the cattle industry.

(2) Social interactions and neighborhood effects have been incorporated into economic models to explain an expanding array of behaviors and outcomes (education, health, poverty, employment). This project examines how social networks affect land use choices of farmers in the Amazon. Farmers make land use decisions based on expected profits from alternative options. These expectations are influenced by information on available farming technology and options farmers gather from 'neighbors'. The study region of Ouro Preto do Oeste was settled less than 40 years ago by colonists from many different states in Brazil, who did not have any significant control over the specific plot that they were assigned. In this situation, farmer associations of various types can form the primary social networks through which farmers learn about alternative forms of land management strategies and share experiences with each other. Thus, a neighborhood for a farmer can be defined either by physical proximity (as has been common in research on social interaction effects in developing regions where people reside in communities) or according to social relationships fostered through participation in these farmer associations. As farmer associations (including cooperatives, unions, and neighborhood organizations) have significantly increased since 1990, they have become central to many strategies for promoting sustainable land use. This part of the research attempts to

estimate the impact that social interactions from participation in these associations have on land use decisions.

To accomplish this, the following tasks were undertaken:

(i) Interviews with staff at the local government extension agency (Emater - Instituto Paranaense de Assistência Técnica e Extensão Rural) were conducted to gather information on creation, membership and type of services provided by each association. In order to obtain government credit, each association has to register with Emater each year. Thus, all the municipal offices of Emater in the study area had information on these associations since 1996, the year when the first round of survey was conducted in the region.

This information was merged with the household survey data collected in the 1996, 2000 and 2005 surveys to verify the data collected on participation in farmer associations and similar social organizations. Spatial econometric models will be used to empirically assess the role of social interactions on land use choices of farmers.

From survey in 2005:

Name of household head _____

Number of Survey _____ Municípality _____ Road _____

Do you remember being interviewed in 2005? ___ yes ___ no

1.01) Name of respondent _____

1.02) Relation with respondent in 2005 _____

1.03) Size of lot? _____ (units)

1.04) Did you change the size of the lot since 1996? __ yes __ no *(if no, go to 1.08)*

1.05) How did you change the lot size? Increased or Decreased? _____

If increased.....

1.06) Size of other lot _____ 1.06a) when did you buy other lot? _____

1.06b) Where is the other lot? Lot number _____ road ____ municipality ___

If decreased…..

1.07) Why decreased? _____

1.08) How much of pasture did you have on each lot since 1996?

_____ now _____ 2005 _____ 2000 _____ 1996 (this lot)

_____ now _____ 2005 _____ 2000 _____ 1996 (other lot)

1.09) If increased between 1996 and 2005, what type of land cover was transformed into pastures?_____

1.10) If decreased between 1996 and 2005, why did you change?

_____

1.11) When did you start selling milk? _____

1.12) Which laticinio did you start selling milk to? (***mention if there was other name***

_____ laticínio _____ other name

1.13) Which other laticinios could you sell to _____ when you began?

_____, _____, _____

1.14) Why did you choose this laticinio to sell milk?

_____

___ knew manager (or other people) ___ trcuk driver was friend
(how often do you talk? _____) *(does he live on same road __ yes __ no)*
___ only option ___ better price
___ neighors sold to same laticinio ___ credibility or reputation
___ because this laticinio wanted to but cold milk ___ received money in advance

1.15) Have you changed laticinios since then? ___ yes ___ no

1.16) Which other laticnios (provide name and year when laticinio changed?
[A] Name _____ Município _____ year 1996
[B] Name _____ Município _____ year 2000
[C] Name _____ Município _____ year 2005
[D] Name _____ Município _____ year 2006

1.17) Why did you change laticinio? _____

___ knew manager (or other people) ___ trcuk driver was friend
(how often do you talk? _____) *(does he live on same road __ yes __ no)*
___ only option ___ better price
___ neighors sold to same laticinio ___ credibility or reputation
___ because this laticinio wanted to but cold milk ___ received money in advance

1.18) How many cows did you own the following years? (separate this/other lot)

Milk producing	2006	2005	2000	1996
number				
lactating				
Girolanda (genetic)				

Cows for beef - _____ now _____ 2005 _____ 2000 _____ 1996
Genetic variety _____ _____ _____ _____

1.19) How many litres were produced per day and what was the price per litre/ day?

year	Wet season		Dry season		Litres/ cow
	number	Price	number	Price	
2006					
2005					
2000					
1996					

1.20) What is he BONUS that you earn per litre now?
_____ now _____ 2005 _____ 2000 _____ 1996

1.21) What was transportation charged by the milk truck the following years?
_____ now _____ 2005 _____ 2000 _____ 1996

1.22) Why did the price of milk change between 1996 and 2005?

___ quantity ___ quality (ordenha)
___ sold cold milk ___ competition among plants

1.23) Which laticinio trucks passed infront of the property following years?

Year 2006 -
_____

Year 2005 -
_____

Year 2000 -
_____

Year 1996 -
_____

1.24) Where do you obtain the following information from?

	Pasture management (Gradeacao)	More milk production (genetic, nutricao)	Choice of laticinio
Friends			
Parents			
Neighbor on same secondary road			
Niehbors living in front (3)			
Neighbors on the side (2)			
Members in same church			
Government agencies			
Members of same association			

1.25) DO your neighbors sell milk to the same laticinio? __ yes __ no

1.26) If no, why do they choose other laticnios? _____

1.27) do your neighbors receive the same price for milk?
___ higher ___ lower ___ same (if same, go to 1.29)

1.28) If more or less, why is the price different?_____

1.29) How many families does the farmer know (friends, neighbors, members of same church/association) who sell to same laticinio? ___

1.30) From the folloiwng list of milk producers (same road), who do you know? How?

Laticinio	Apellido e quantidade	Numero do lote do vizinho	Onde voce encontra (Igreja, associacao)	Quantas vez
Mesma				
SMR/PAR				

1.31) Do you receive any assistance from the laticínio(s)? __ yes __ no *(se no, go to 1.33)*

1.32) If yes, what assistance do you receive?
____money advance ____ info on technology to produce milk
____ info on pasture and herd management

1.33) Do you receive assictance from the government on cattle?
____ yes ____ no *(se no, go to 1.36)*

1.34) Which govt agencies do you get help from? _____

1.35) What type of assistance did you receive? _____

1.36) Do you receive assictance from any **associations/ organizations** for farmers? ___ yes
___ no *(if no, go to 1.39)*

1.37) Which associations provide assistance for cattle? _____

1.38) What assistance did you receive? If you did, what was it?

1.39) Have you made any investments to improve pasture productivity?
___ yes ___ no *(if no, go to 1.41)*

1.40) Please provide information on the following aspects? (seperate this/other lot)

Type of investment	Year invested	Amount invested	How many hectares did that affect?	Invested for milk or beef?
Plant grass				
till				
Construct fence				
feed				
Herbicides				
weeding				

1.41) Have you made any investments to improve milk productivity?
___ yes ___ no *(if no, go to 1.43)*

1.42) Please provide information on the following aspects? (seperate this/other lot)

Type of investment	Year invested	Amount invested	How many hectares did that affect?
Reproductive cows			
Mineral, Vitamins			
Cement-floored corral			
Mechanical milker			

1.43) Do you think the stocing density will
___ increase ___ decrease or ___ stay same in next 5 years?

1.44) Have you received any credit to invest in milk or pasture? ___ yes ___ no *(if no, go to 2.01)*

1.45) When did you receuve the credit? _____

1.46) How much did you receive? _____

1.47) Where did you receuve it from? _____

1.48) How was the money utilized? _____

****

2.01) Do you sell cows for beef? ___ yes ___ no *(if no, got to3 3.01)*

2.02) When did you strart selling cows to slaughterhouses? _____

2.03) Which slaughterhosue do you sell to now? _____, _____

2.04) Why did you change slaughterhouses? _____

2.05) How do you transport cows to the slaughterhouse? _____

2.06) How much does transportation cost?_____

2.07) How many cows did you sell and for what price in the following years?

Year	Adukt cow	Price per unit	calves	Price/calf	Name of slaughterhouse	location
2005						
2000						
1996						

2.08) Which is more important to household income?
___ milk ___ beef

2.09) Why is it more important? _____

2.10) In case of emergency (health, catastrophe), which is the source for quick cash?
__ ask money from parents __ ask money from friends
__ sell beef cow __ sell milk cow
__ sell lot/ house/ car

2.11) Do you maintain the pasture differently for milk and beef?
___ yes ___ no

2.12) If yes, how is it different? _____

2.13) How many families sell cows for beef? __

2.14) How many families does the farmer know (friends, neighbors, members of same church/association) who sell to same slaughterhouse? _____

2.15) Are the majority of the farmers on the road members of same church?

___ yes ___ no

****

3.01) Do you sell crops? __ yes __ no *(if no, END)*

3.02) Where do you obtain the following ifnormation from?

Product	How much did you sell in the following years? Kg/Sack	Who did you sell to?	Location	Selling since when	How many families on the same road sell crops (most,some, few)
	1996 – 2000 – 2005 –				
	1996 – 2000 – 2005 –				
	1996 – 2000 – 2005 –				

3.03) Why did you choose these cerealistas (traders)?

_____

___ better price ___ knows managaer for long time
___ friends sell to same trader ___ trader collects product from lot
___ members of same church sell to the trader

3.04) How do you transport products? _____

3.05) Do you pay for transport? ___ yes ___ no
3.06) If yes, how much do you pay? _____

3.07) If no, how much do you think it may cost?_____

3.08) How many families does the farmer know (friends, neighbors, members of same church/association) who sell to same trader? _____

3.09) Are most of the same from the same church?___ yes ___ no

3.10) How many traders do you have the option to sell these products to? _____