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ORIGINAL ARTICLE

Labor scarcity as an underlying cause of the increasing prevalence of deforestation due to cattle pasture development in the southern Yucatán region

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Abstract We investigate the problem of understanding the drivers of land use and its change in the southern Yucatán region. Our household data drawn from villages across the region show that as the amount of land devoted to crop cultivation has fallen, the amount of land devoted to pastureland has increased. We investigate this trend using a suite of three reinforcing investigative methods: (1) description and interpretation of direct evidence; (2) comparison of expected returns across main agricultural land uses; and (3) econometric modeling. We find that the increasing prominence of cattle ranching, or the prelude to it by planting pasture, is in part because of the constraints households face in family labor, one of the household's key resources, and the relatively lower labor requirements of cattle ranching. The activity of cattle ranching fits particularly well with the constraints and incentives faced by the typical household in the region.

Keywords Deforestation · Land use change · Modeling agricultural · Yucatán

Introduction

The southern Yucatán (SY) region is one of the world's important forested regions, registered by the presence of the Calakmul Biosphere Reserve and the Mesoamerican Biological Corridor, and thus understanding the behavioral drivers of land use and land cover change in the region is crucial. We develop a thesis that resource constraints and incentives, such as profitability, play an important role in agricultural land use decision-making, shaping the landscape of the SY. Investigating land subject to individual household agricultural use, we find that pasture creation for cattle ranching acted as the main driver of deforestation in the 1997–2003 time period when deforestation is defined as land under agricultural use whether clearance of primary or secondary forest was cleared. The amount of land devoted to pasture increased over that time period, more than offsetting a decrease in the amount of land under crop cultivation. Cattle ranching is a well-known proximate cause of deforestation in Latin America but has not been investigated to a significant extent in the SY.

We explore the increasing prevalence of pasture for current or anticipated cattle ranching as measured by both increasing incidence and extent of land devoted to pasture. We use three methods to investigate this question: one descriptive and two different analytical modeling frameworks. We find that the relatively low labor requirements of pasture, in combination with relatively scarce labor and abundant land, play a role in the diffusion of cattle ranching and pasture. Moreover, cattle ranching frees up labor that can then be used for other income generating activities, such as migration, consistent with the diversification of income sources explored by Radel, Roy Chowdhury, and Schmook in this volume.

This increased migration and the spread of pasture for cattle is consistent with a hollow frontier land use trajectory (Rudel et al. 2002). Despite an outflow of people, the land remains largely denuded, occupied by low-value agriculture (e.g., extensive cattle ranching), and thus,

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"hollow." The contrasting forest transition trajectory moves from initial settlement to increasing industrialization and gains in agricultural productivity that yield significant reforestation (Defries et al. 2004). This is the North American and European experience of recent centuries (Mather and Needle 1998; Walker et al. 2002). In the conclusion, we return to these themes as they apply to regional environmental change in the SY.

Methods

Our three methods each rely on household level survey data collected in partnership with Birgit Schmook during fieldwork conducted over 2 years, 2003–2004. A stratified two-stage, cluster design (Deaton 1997) with a first stage involving random selection of ejidos (these can be thought of as analogous to villages) and a second stage involving random selection of landholding households within each selected ejido. The foundation for our data was the 1997 sample collected by Southern Yucatán Peninsular Region (SYPR) Project (Geoghegan et al. 2001). We located 138 households from the original sample and added households and two ejidos in a way to enhance representativeness, resulting in 174 households in 13 villages. For a detailed review of the entire spectrum of data collected, including all variables and answers to open-ended questions about adoption decisions and risk and agricultural strategies, see Busch (2006).

We use these data as inputs to three methods of inquiry: (1) description and interpretation of direct evidence; (2) comparison of expected returns across main agricultural land uses; and (3) econometric modeling. We collected both quantitative data and responses to open-ended questions that covered a range of topics, strategies for climate risk management, reasons for having started, quit, or never started, and reasons that the household owned pasture but not cattle at the time of data collection. Reporting and interpreting these results is the first of three methods we use. We then compare economic returns to different land uses, using three measures of returns across the major land uses: chili, maize, and cattle. The three types of returns are total returns, returns per hectare, and returns to labor. Total returns are defined as profitability per unit of output. This is the typical economic point of reference; however, in frontier areas where resource constraints loom particularly large other metrics also provide insight. The per hectare metric for characterizing land-based production reflects the fact that many farmers in the study area are inclined to conceptualize questions of production this way. The measure of returns with respect to labor utilized offers insight into the important decision on allocation of labor across activities. Finally, we develop econometric models to test hypotheses concerning the determinants of the choice of activities to include in the agricultural portfolio and area devoted to maize, chili, and pasture.

This research reports both survey and modeling results. Owing to the complexity and linkages of these results, presentation of them is facilitated by fusing results and their discussion for both the survey data and modeling outcomes. In addition, to foster coherency, the model specification and hypotheses are woven into the results-discussion of the modeling exercise. The hypotheses are grounded in the literature on deforestation, smallholder farming, and cattle expansion in tropical forest areas.

Results

Descriptive evidence

SY residents are mostly smallholding farmers who get the largest share of their income from agricultural land use, consisting mostly of jalapeno chili (hereafter, "chili"), maize, and pasture for cattle. The region is far from major markets, which has constrained development of alternative commercial agricultural opportunities beyond these main three land uses, which consist of 99.7% of the agricultural activities in our sample. Table 1 profiles the prevalence of these activities within our sample.

Almost every household grows maize (155 out of 174 households in our survey). Maize cultivation is mostly for subsistence, using shifting cultivation, where forest is felled and burned to enrich the soil and cultivated for a period of 2–4 years. The land is then left for forest regeneration for 10 years or less (Schmook, this volume) and reused. In our sample, maize requires 52 days of labor per hectare on average, 41 unpaid and 11 paid. Forest clearing adds 15–25 days depending on the age of forest.

Chili is the pre-eminent commercial crop in the SY, in which intermediary buyers purchase almost all output for

Table 1 2003 Agricultural land use profile

Variable	Observations	Mean*	SD*	Minimum*	Maximum*
Land holding	174	68.8	39.1	1	200
Have maize	155	3.96	3.78	1	28
Have pasture	90	20.5	27.8	0.5	190
Have chili	74	1.16	0.722	0.25	4

* In each case, except for number of observations, units are hectares of land

transportation to market centers. There is significant price risk for farmers, as prices fluctuate widely from year to year based on the quality of the harvest elsewhere in Mexico (Keys 2004, 2005). The climatic risks—drought and hurricanes—are also serious for this sensitive crop. Farmers cultivate chili using the shifting method employed for maize but almost never planted on the same plot for more than a single season due to depletion of soil fertility.

Compared to maize, chili uses more labor on a per hectare basis, and a higher proportion of paid labor. This is due to the concentrated labor input requirements of the chili harvest. Family labor is rarely sufficient for substantial chili cultivation. The chili harvest takes place in two to four (usually three) distinct phases. The fruit is cut while still green, and this induces the plant to fruit again. Timing is essential. Each harvest phase should be carried out in just 1 or 2 days and requires somewhere from 15 to 30 days of labor per hectare. For chili, we find a mean value of 117 labor days used per hectare of production, 70 in paid labor and 47 in unpaid labor. These results are consistent with the other published results on labor inputs. For example, our finding on labor requirements falls near the middle of their range derived in the task-by-task explication of labor inputs by Fernandez (2002) and Keys (2004).

Cattle ranching offers important risk management and vulnerability-reducing benefits. Cattle are more robust, less vulnerable to climatic extremes and serve as a savings mechanism for people without easy access to banks. Cattle feed primarily on pasture grass, with an optimal stocking rate of approximately one adult animal per hectare (or hectare and a half) per year. This and other aspects of typical cattle ranching practice are derived from in-depth interviews with government and agricultural extension specialists in the SY as well as ranchers with well-developed and successful operations. At this stocking rate, and with proper management, pasture can be maintained indefinitely. Our survey results for pasture show that the rate of adoption of cattle ranching has steadily increased from the time the first household in our sample began cattle ranching in 1976. Our household–*ejido*-based sampling method did not consider another type of cattle ranching operation in the SY region: *ranchos*. Ranchos are much larger in area than the upper end of pasture maintained by ranchers in our sample and operate as individual entities outside of a village structure. There are approximately 67 of these in the region, and together, they represent about 200 km^2 or roughly 3% of the SY region's land area (Vance et al. 2004). The survey year of 2003 has the highest rate of adoption in any year. Thirteen households began cattle ranching that year, 7.5% of our sample. Four of the five largest annual increases in the rates of adoption occurred over the 5 years from 1999–2003. Due to the cash and labor constraints, the typical household farmer in the SY seeks to establish cattle ranching operations by building up their pasture and infrastructure over a series of many years, often without having livestock. Cattle ranching requires establishment of fencing and artificial ponds (known locally as jagueys) to collect water to sustain cattle in the dry season. A common strategy is to undertake crop cultivation first and then to plant pasture grasses after soil fertility is depleted to the point that crop productivity has significantly diminished. Two-thirds of the pasture managed by households in our survey was created followed this strategy. For a full breakdown of land type prior to establishment of pasture, see Busch (Busch 2006; Table 2.15, p. 47). This is not to suggest that the dominant land use cycle involves planting pasture after crops. To the contrary, more often cropland returns to secondary forest cover, a phenomenon that Schmook explores in this volume.

Given the pasture-to-ranching development process, it is to be expected that some ranchers in the early stages might be without cattle. About 47 of the 90 households with cattle pasture did not have any cattle on their pasture at the time of our survey. Similar results were found in the earlier survey. Klepeis and Vance (2003) argue that farmers are planting pasture in anticipation of future government subsidies for cattle ranching.

The region has had some experience with ill-fated cattle ranching experiments. The largest areas of invasive bracken fern in the SY region are due to failed cattle pastures (Schneider 2006). Among the 13 ejidos in our survey, one, Tomas Garrido experienced a large-scale die off shortly after the introduction of Holstein cattle; the type is well known to be inadequate for the environment, and this case proved the point. A different type of cattle was introduced, and now Tomas Garrido is second highest ejido in terms of rate of adoption of cattle. Overall, we found a relatively low rate of abandonment of cattle ranching once initiated. Eight households of 174 households have quit permanently, due to water and cash constraints. Five households have quit temporarily, have no pasture now, but intend to start again once the resources can be marshaled for infrastructure development.

About 43 of 90 households that have established and maintain cattle pasture actually own cattle themselves. This group with cattle and not just pasture maintains on average 22 head of cattle on their 29 ha of pasture. In sum, they graze 946 head of cattle (with animals less than a year old values at half of an adult) on 1,286 ha of pasture. About 27 households have at least 10 head of cattle.

The data tell a clear story of the takeoff in adoption of cattle ranching in recent years, and our survey results provide some direct evidence that cattle ranching will continue to spread to households that have never undertaken the activity before. Of the 71 who have never attempted to develop a cattle ranching operation, only 19 had no interest in doing so, while 24 of the 71 non-adopters had a specific plan to begin within 3 years. Yet a reversal is clearly is also possible. Large swaths of bracken fern on prior pastureland serve as a reminder of this.

With this observed increase in pasture, we next consider the overall changes in land covers in the region between 1997 and 2003, given in Table 2. As land devoted to crop cultivation fell, the expansion of pasture for cattle ranching increased by an even larger amount, resulting in a net loss of forest cover over this time period.

Pasture effectively relaxes soil and labor constraints, radically altering the smallholding farmer's capacity to transform the land. In practice, farmers most often accumulate pasture over time by planting grasses after cultivating crops. The effect is that pasture substitutes, at least partly, for land that would have otherwise been returned to secondary forest status. Table 3 shows that cattle ranching has the potential to greatly increase cumulative deforestation in the SY.

In this volume, Schmook identifies a trend toward intensification in crop cultivation cycle, but we also see a trend of increased extensive use of land for pasture. As we explore next, the relatively modest labor requirements for cattle ranching are one of its defining features. Thus, our finding of the increasing prevalence of cattle ranching fits well with those of Radel, Row Chowdhury, and Schmook (this volume), who find increasing diversification of household income sources, which requires that agricultural activities not utilize all of the household's labor.

Expected returns

For maize and chili cultivation, we employ the measures of expected annual returns. For cattle ranching, we develop a multi-year simulation, an idealized, constructed scenario, to account for the typical long-run development conditions that exist in the SY region. We assume a discount rate of 20% and 10-year time horizon to find the net present value. The cattle simulation constructs a prototypical multi-year scenario for how a fully mature cattle ranching operation would be developed. This is not a Monte Carlo simulation. Such a representative scenario is necessary because of the wide variation in the way cattle ranches are actually developed on the ground. In the prototypical scenario, cattle are not purchased until the second year. Breeding and sales achieve an optimal stocking rate and income flow over time. The simulation uses cost and input data from surveys in addition to information obtained from experienced ranchers and extension specialists. We use a discount rate to reflect the relative lack of availability and the economic hardship common to the area that makes it more difficult to be "patient" in waiting for long-term investments to pay off. The table below gives the average of the present value over a 10-year time horizon. The reasoning behind the assumptions underlying this long-term simulation, and full details on all the cost, harvest, and price data underlying the returns presented in Table 4 can be found in Busch (2006, Chap. 2).

Cattle provide the lowest returns on both the $/ha and $/kg measures but does best from the perspective of returns to labor. In this way, its fits well with the resource bounds of smallholding farmers in the SY with a relative abundance of land. Labor and cash constraints bind sooner and

Table 2 Changes in land cover: 1997–2003

($N = 138$)	Maize (%)	Chili (%)	Pasture (%)	Forest (%)
Change in mean land share 1997–2003 overall	−1.6	−0.07	+4.0	−1.7
Change in mean land share 1997–2003 per annum	−0.27	−0.12	+0.67	−0.28

Define forested land as land not currently in use for an agricultural purpose

Table 3 Land use for different types of households—mean 2003 data

Type of household	Number of cases	Total (ha)	Pasture (ha)	Maize (ha)	Chili (ha)
All	165	15	11	3.7	0.52
Non-adopters	75	3.7	0	3.1	0.56
Adopters	90	26	21	4.2	0.49
Mature adopters	26	43	38	4.5	0.47

Adopters are defined as those with pasture for cattle. Mature adopters are those that have had pasture for cattle for at least 10 years. Only households with at least ¼ hectare in use for agriculture are included. Nine cases with less than ¼ hectare of agriculture land use include instances in which the head of household had lucrative off-farm employment, had migrated to the US or another part of Mexico in search of employment, or was disabled

Table 4 Comparative economic returns across land uses

Profit measures ($ = pesos)	Chili	Maize	Cattle
$ per HA of land cultivated	6,500	1,500	490
$ per kg of output	0.84	1.0	0.48
$ per labor day	56	35	88

These are expected returns for chili and maize, and simulated returns for cattle, based on the net present value of profits over a 10-year period discounted at 20%

more often for households in the SY. These simulation results support our hypothesis that labor, not land, is the binding input constraint affecting landowner's decision-making on land use allocation in the region.

The type of return reported earlier for cattle ranching—an idealized, return based on annualized return over 10 years—remains an aspiration and not a reality for the vast majority of households. At the same time, the estimate of long-term returns that we find in our simulation exercise, 490 pesos/ha, is rather close to the per hectare returns observed for the 22 households that had any cattle sales in 2003, which earned 585 pesos per hectare. To the extent that engaging in sales of cattle represents having achieved a minimum level of operational development, which will be true sometimes though not always (it could be that an emergency need for cash has forced a sale); this result is supportive of the results of our simulation.

Econometric modeling

We estimated econometric models of each of the three land uses: pasture, chili, and maize. Summary statistics for the data used are found in Table 5.

The approach taken here builds on earlier SY research. Vance and Geoghegan (2004) develop a two-part econometric model to investigate the potential differences between the discrete decision of market participation and the continuous decision of area planted for maize and chili. We use a similar two-part modeling approach, with the first part considering the choice to engage in the land use or not (discrete choice) and the subsequent part considering then how much to land to allocate to a particular land use (continuous decision).

The fact that significant fractions of farmers do not participate in a particular land use type—a limited dependent variable problem—must be accounted for in modeling. If it is not, then biased coefficients could result. Manning et al. (1987) make a strong case for a simple (decoupled) two-part model for managing the issues raised by limited dependent variables. A two-part model de-links the discrete and continuous processes, with Probit estimation on 0/1 values for the whole sample in part one and ordinary least squares (OLS) estimation only on observations with positive values in part two. Another more sophisticated approach is Heckman's (1979) selection model that explicitly accounts for selection bias in the group that chooses to engage in the activity. Manning et al. (1987) conduct a Monte Carlo experiment with data generated via a true Heckman process and find that a two-part model performs better than the Heckman approach even in this case where data are truly produced by the process hypothesized by Heckman. The two-part model is robust across a wide range of parameter values, while the Heckman model is unstable, highly sensitive.

The inherent inter-relatedness of land use decisions on the farm gives a simultaneous equations approach some intuitive appeal. In addition to two-step and Heckman models, we also test a specification that treats the three agricultural activities as a system by following Tauchmann (2005), who develops a two-step procedure to estimate a multivariate Heckman model.

Similar to Pichón's (1997) study of Amazonian deforestation, our dependant variable in analyzing the amount of land given to a particular activity is the land share for the land use in question, which is defined as the fraction of a household's land going to a particular land use. The land share approach does offer attractive properties for modeling a system of equations, the Tauchman approach. That said, the land share approach is not very different from one in which the dependent variable is defined as absolute land area. It is simply a normalization of the amount of land in each land use by the total household land area. When we run regressions with absolute land area instead of land share, the results are very similar, the same significant variables are the same and have the same signs.

Busch (2006) discusses these modeling approaches further and reports results for each: two-step, single equation Heckman, and multivariate Heckman. Test statistics from the Heckman models did not support that approach for either the multivariate Heckman or the single equation Heckman models, except in the case of cattle ranching. In the end, because of the Manning et al. (1987) result described elsewhere and the fact that we are not seeking to make out of sample predictions in this paper, we report results of the two-part model for each land use. Note that when we look at results across the three model types (two part, single equation Heckman, multivariate Heckman), there is no variation across which variables are significant, no changes in sign, and remarkable similarity on the magnitude of coefficients. Therefore, these results provide a type of sensitivity analysis as well as some confidence about the robustness of our findings. The modeling story would not be different if we were looking at results from one of the other model types.

A final note on how we arrived at the results that we report. Though guided by economic theory (Goetz 1992;

Table 5 Descriptive statistics—survey data

Variable (units)	Mean	SD	Min	Max
Pasture share (all 174 observations)	0.140	0.222	0	1
Pasture share (89 observations; those with pasture)	0.274	0.245	0.005	1
Chili share (unconditional, 174 observations)	0.009	0.020	0	0.214
Chili share (74 observations; those with chili)	0.022	0.026	0.002	0.214
Maize share (unconditional, 174 observations)	0.073	0.099	0	1
Maize share (155 observations; those with maize)	0.082	0.102	0.007	1
Family labor supply (scaled at 1/10)	0.353	0.152	0.1	0.8
Full time work (1, 0)	0.149	0.358	0	1
Non-farm income ($10,000 pesos)	0.056	0.133	0	0.768
PROCAMPO ($10,000 pesos)	0.416	0.444	0	3
Cattle credits ($10,000 pesos)	0.131	0.500	0	4.9
Land holding (100 hectares)	0.688	0.391	0.01	2
Rainfall (meters of rainfall)	1.10	0.097	0.934	1.27
Good soil (1, 0)	0.741	0.439	0	1
Distance to parcel (10 s of kilometers)	0.595	0.612	0.01	3
Distance to nearest market (100 s of minutes)	1.00	0.375	0.45	1.8
Own pickup truck (1, 0)	0.172	0.379	0	1
Years of education	3.61	3.61	0	16
Household head under the age of 31 (1, 0)	0.115	0.320	0	1
Residence in ejido Nicolas Bravo (1, 0)	0.109	0.313	0	1
Number of household amenities	6.18	3.32	0	13
Household head speaks Chol as first language (1, 0)	0.115	0.320	0	1
Household head speaks Maya as first language (1, 0)	0.103	0.305	0	1
Residence in central Calakmul (1, 0)	0.213	0.410	0	1
Residence in the chili zone (1, 0)	0.293	0.456	0	1

Key et al. 2000) and previous work as explained previously, we undertook a "let the data tell the story" approach to final specification of the model. We tested for non-linearity in many variables—age, land holding, family labor supply, non-farm income, and indeed any continuous independent variable—via both quadratic terms and sets of fixed effects, which offer the greatest parametric flexibility. Where we found significant results, the variables have been included in the final specification. So, for example, we undertook testing for demographic effects using fixed effects on age by decade. The only statistically significant result that we found is this "under 31" variable.

Modeling hypotheses

A key issue with two-part models is to be able to separate the factors that affect the discrete decision from the continuous one. Building on the previous work of Vance and Geoghegan (2004), as well as by Goetz (1992) and Key, Sadoulet and de Janvry (2000), identification of the model is achieved by including in the discrete ("selector") equation variables that proxy for fixed transaction costs, such as the time, effort, and other resources expended in marketing the agricultural product that affect the initial decision to engage in an activity or not. However, these fixed costs do not affect the subsequent decision of how much of the activity to engage in, so these variables do not appear in the continuous ("regression") equation. Therefore, these fixed costs variables *only* appear in the selector equation, while other variables are included in both the selector equation and the regression equation.

The fixed costs variables include language, location, and wealth. Following Vance and Geoghegan (2004), we hypothesize that first language can impose extra fixed costs of adoption. People less in the mainstream of society due to their group identification may well find it more difficult to access the market. We hypothesize that having Chol or Maya as a first language will negatively affect adoption for mainly commercial activities, such as pasture or chili, but as all of these farmers grow maize, these variables are not included in the selector equation for maize. We also include location variables in the selector equation. Similar to Vance and Geoghegan (2004), we include a dummy variable for residence in the *ejido* of Nicolas Bravo, a grain depot, which would reduce the fixed costs of marketing maize. At more than 5,000 residents, the *ejido* is one of the largest in the region and is located along the main highway. Other regional dummies are included to control for the improved market access location of the "Central" region, and the prominence of chili cultivation in the "Southern" region, where a culture of chili cultivation, including more advanced production techniques, exist. To control for wealth effects that could influence the initial engagement in different land use choices, we include a proxy measure for the sum of household amenities, such as a concrete floor, refrigerator, bathroom, television, and so forth.

The other explanatory variables in the econometric model represent the resource constraints on land, labor, and cash as well as incentives from our theoretical framework. We include variables measuring the amount of family labor supply, a dichotomous variable for off-farm full-time employment, and the amount of off-farm income. The hypothesized effects of each of these variables differ for the three land uses. As chili is very labor intensive, we expect that a larger family labor supply would be expected to increase the probability of both selection and land use area, while off-farm employment, all else equal, would have the opposite effect. As we have emphasized, one of the advantages of cattle ranching is its low labor requirement, so labor variables, including the full time variable, are not expected to affect pasture. However, there are substantial monetary outlays to cattle ranching (the cattle themselves, infrastructure, especially fencing and jagueys). Thus, we anticipate non-farm income to have a positive effect on engagement in cattle ranching and area devoted to pasture. Maize can be cultivated with no cash inputs although could be used to purchase labor, so we hypothesize a positive effect.

Our a priori hypothesis is that the land share will decrease as the amount of land that the household has access to increases (i.e., the variable will have a negative coefficient in the regression equation). This claim follows from the hypothesis that resource constraints are critical determinants of land share for these crops. In the case of maize and chili, the empirical reality is that eventually resource constraints bind and land beyond the amount that can be cultivated remains in forest and the land share for maize or chili falls as the land holding increases. In the case of pasture for cattle, soil fertility is not a constraint, and labor constraints are less binding, and a few households have completely transformed their land holding to pasture. Yet, for most households, labor constraints across economic activities (agricultural and not) and liquidity constraints still constrain the amount of pasture. The economic literature on technology adoption has demonstrated that larger farm size increases the probability of technological adoption, as a larger farm size allows fixed costs of adoption to be spread over a larger production area, and this reduces fixed costs per unit of output (David 1969; Just and Zilberman 1983). Thus, we expect a positive coefficient on the land holding variable in the selection equation, especially in the case of cattle ranching, which has the largest fixed costs of all the main land uses. Given the relatively low return per hectare, access to a minimum amount of land would be necessary to achieve a reasonable standard of living.

We use the changing age of the household head as a proxy for location along different points in the household lifecycle. Our null hypothesis is that the probability of adoption of cattle ranching increases with age of the household head to a point and decreases thereafter. This is based on a lifecycle theory of smallholder agricultural development that identifies a number of factors that push frontier households to cultivate fast-growing annual crops and not cattle during the early stages of household development (Walker et al. 2002). We also expect that a higher age of the household head will produce larger areas of pasture for cattle in the regression equation, as these households will have had more time to develop a mature cattle ranching operation.

Greater education may speed learning and may indicate greater capability or willingness to expend effort, thus increasing expected profits (McWilliams and Zilberman 1996). A priori, we expect education to increase the probability of selecting in and the amount in the regression equation, but only up to a point. For households with eight or more years of education, the opposite effects are expected because of the greater probability of successful off-farm, non-agricultural employment (including migration to secure such off-farm employment) (Sadoulet et al. 1998; Vance and Geoghegan 2004).

We include measures of rainfall (18 year average) and soil quality (good or not). We expect a positive relationship between more rainfall and adoption and extent of pasture. Cattle are very dependent on water. They require from 50–70 l of water on hot, dry days. Thus, we expect rainfall to be a positive factor for cattle, because the more humid areas have slightly shorter dry seasons and the vagaries of rainfall are less pronounced; *jaqueys* (constructed ponds for water storage) are less likely to desiccate. For chili and maize, we do not have an expectation, a priori for the rain variable, as these plants are not grown in areas with insufficient rainfall. Good soils include rendzina and other mollisols and bad soils include other soils: litosols (thin) and vertisols (poorly drained clays). We expect better soil to favor chili production, while maize and pasture are less sensitive to soil types so we do not have a priori expectations for these.

We have variables for distance to the plot and distance from village to regional market centers. A more remotely located parcel adds costs to production and marketing, thus reducing the likelihood and extent of engagement in a commercial land use. However, this is not the case for chili where intermediaries take care of transportation to market (though not transportation from the parcel). In this sense, for farmers in more distant, isolated areas, chili enjoys a relative advantage, compared to other land uses because farmers need only get the product to a designated location near their e*jido*. Therefore, we anticipate a positive sign on the distance to market variable for chili. We also included a dichotomous variable for truck ownership, as we expect that this would reduce the transaction costs imposed by distance.

The model includes two types of government program interventions, PROCAMPO and credits for cattle ranching. PROCAMPO is a rural income support program phased in after NAFTA and tied to the 1994 land use area. PROCAMPO provides yearly cash payments to farmers. The cattle credit variables sums credits received over the years in residence in the SY. The hypothesis on cattle credit are clearly positive for pasture land use. Under the same reasoning as non-farm income, our expectation for the effect of PROCAMPO is positive for both pasture and chili peppers, though not for maize.

The following three tables provide econometric results for each of the separate land uses: Table 6 for pasture, Table 7 for chili, and Table 8 for maize. Statistical tests were performed to test whether the selector equation and regression equation were independent for each land use. Results for chili and maize found no statistical evidence for estimating the two equations simultaneously, while the result for pasture rejected the null hypothesis of independence. Therefore, the results reported in the following sections for pasture use a Heckman selection model (Heckman 1979). As a reminder, the selector equations use all the household observations, while the regression equations only use the observations for households that engaged in the activity.

Discussion

For the pasture equations (Table 6), the coefficient on cattle credits and PROCAMPO SUBSIDIES are positive and statistically significant in both the selector and the regression equations, as hypothesized. The distance to

Table 6 Econometric results for pasture (two-part model)

Explanatory variables and other row labels	Probit (selector eqn)		OLS regression (regression eqn)	
	Coefficient	*p*-Value	Coefficient	*p*-Value
Family labor supply	−0.286	0.734	−0.009	0.949
Full-time job	−0.303	0.468	−0.048	0.506
Non-farm income	0.031	0.979	−0.022	0.927
PROCAMPO subsidies	0.719	0.070*	0.140	0.002***
Cattle credits	2.28	0.003***	0.099	0.002***
Land holding	0.142	0.697	−0.075	0.258
Rainfall	0.913	0.004***	0.077	0.007***
Good soil quality	0.185	0.509	−0.042	0.401
Distance to plot	0.455	0.067*	−0.078	0.047**
Distance to market center	−1.25	0.136	−0.284	0.000***
Own a pick up truck	0.249	0.482	−0.001	0.991
Household head education	0.050	0.195	0.005	0.446
Household head under 31	−0.845	0.044**	0.007	0.938
Nicolas Bravo	−2.90	0.000***		
Household amenities	0.140	0.007***		
Chol was first language	−0.778	0.073*		
Maya was first language	0.448	0.283		
Central Calakmul	−0.182	0.766		
Southern Calakmul	0.781	0.125		
Constant	−10.4	0.001***	−0.281	0.346
Log-likelihood	−79.1			
Chi-square & *p*-value	82.9	0.000		
"Pseudo R^2" or R^2	0.344		0.512	
Adjusted R^2			0.427	
Observations	174		89	

* Significant at 10% level
** Significant at 5% level
*** Significant at 1% level

Table 7 Econometric results for chili (independent two-part model)

Explanatory variables and other row labels	Probit (selector eqn)		OLS regression (regression eqn)	
	Coefficient	p-Value	Coefficient	p-Value
Family labor supply	0.585	0.527	0.058	0.000***
Full-time job	−1.55	0.051*	−0.024	0.123
Non-farm income	1.29	0.467	0.112	0.006***
PROCAMPO subsidies	0.726	0.035**	0.011	0.100
Cattle credits	−0.150	0.687	−0.011	0.210
Land holding	0.654	0.089*	−0.043	0.000***
Rainfall	0.213	0.535	−0.011	0.004***
Good soil quality	0.150	0.625	0.006	0.248
Distance to plot	−0.176	0.541	0.001	0.825
Distance to market center	0.172	0.845	0.018	0.077*
Own a pick up truck	0.252	0.493	0.021	0.003***
Household head education	−0.060	0.201	−0.001	0.476
Household head under 31	−1.38	0.012**	0.002	0.794
Nicolas Bravo	−1.42	0.155	N/A	
Household amenities	−0.146	0.007***		
Chol was first language	0.846	0.084*		
Maya was first language	−0.294	0.571		
Central Calakmul	0.163	0.805		
Southern Calakmul	1.63	0.007***		
Constant	−2.86	0.394	0.114	0.002***
Log-likelihood	−66.2		N/A	
Chi-square & p-value	105	0.000		
"pseudo R^2" or R^2	0.442		0.566	
Adjusted R^2	N/A		0.471	
Observations	174		74	

* Significant at 10% level

** Significant at 5% level

*** Significant at 1% level

market variable is negative and statistically significant in the continuous equation; increased transactions costs decreased the predicted amount of pasture. Having more land and higher average rainfall increases the probability of selecting into having pasture for cattle. Being younger than 31 decreases the probability of having started cattle ranching. This is consistent with our hypothesis that the rate of adoption will be highest in middle age. Young adults will have not yet had time to accumulate the resources to overcome the startup cost hurdles. For variables used to distinguish the selector equation from the regression equation, we find three significant variables: speaking Chol as a first language, the household amenities level, and residence in Nicolas Bravo. The language result could reflect a dynamic in which closer identification with the Spanish-speaking majority power class facilitates market access, Chol cultural preferences to focus on subsistence cultivation (see Gurri, this volume), or both. The household amenities index has a positive coefficient: the greater wealth associated with a greater number of household utilities makes these households more likely to cover the fixed startup costs. The one result inconsistent with our a priori expectations was the negative coefficient on residence in Nicolas Bravo. The expectation had been that residence in Nicholas Bravo would decrease the fixed costs of adoption and marketing because of its location nearer the city of Chetumal. Instead, we find the residence in this *ejido*, all else equal, decreases the probability of adoption. It could be that opportunities for non-farm employment associated with the location overwhelm this effect.

For the chili equation results (Table 7), as expected, the coefficient on the variable "works full time" is significant and negative in both the selector and regression equations for chili. Other statistically significant variables in the selector equation include the PROCAMPO variable, which increases the probability of cultivation, and "under 31," which decreases the probability of cultivating chili. For the regression equation, the statistically significant coefficient was only for the "under 31" variable, counter to our a priori expectation based on the lifecycle hypothesis. Theory would predict that these households should prioritize a high, short-term profit crop like to chili to support a growing family. However, it could be that at the time of our survey, the under 31 cohort had come to see the difficulties

Table 8 Econometric results for maize (two-part model)

Explanatory variables and other row labels	Probit (selector eqn)		OLS regression (regression eqn)	
	Coefficient	*p*-Value	Coefficient	*p*-Value
Family labor supply	1.51	0.303	0.042	0.370
Full-time job	−2.03	0.001***	0.029	0.367
Non-farm income	0.234	0.888	0.125	0.149
PROCAMPO subsidies	−0.082	0.868	0.041	0.021**
Cattle credits	0.044	0.882	0.002	0.868
Land holding	−0.299	0.552	−0.127	0.000***
Rainfall	0.396	0.380	0.001	0.902
Good soil quality	0.932	0.019**	−0.023	0.177
Distance to plot	−0.185	0.549	−0.008	0.558
Distance to market center	−1.09	0.328	−0.026	0.251
Own a pick up truck	−0.218	0.685	0.003	0.889
Household head education	0.106	0.087*	0.004	0.098***
Household head under 31	−1.53	0.010**	−0.001	0.966
Nicolas Bravo	0.171	0.540	N/A	
Household amenities	−0.076	0.348		
Central Calakmul	4.22	0.023**		
Southern Calakmul	2.73	0.006***		
Constant	−5.18	0.313	0.155	0.064
Log-likelihood	−40.0		N/A	
Chi-square & *p*-value	50.1	0.000		
“pseudo R^2” or R^2	0.392		0.339	
Adjusted R^2	N/A		0.278	
Observations	174		155	

* Significant at 10% level

** Significant at 5% level

*** Significant at 1% level

of chili cultivation and decided to wait for the first chance to migrate instead. Three of the variables in the selector equation are significant: the chili zone variable, and the Chol variable both have positive coefficients, and the household amenities variable has a negative coefficient. Three variables are statistically significant only in the regression equation: the family labor supply, non-farm income, and “owns a pickup truck,” all of which increase the amount of land cultivated in chili. Counter-intuitively, the estimated coefficient on rainfall in the continuous equation is negative and statistically significant. One explanation might be linked to the positive, statistically significant coefficient on rainfall for the cattle selector equation. Perhaps to an extent, there is a diversion of the scarce resources available as inputs from chili cultivation to pasture in areas that are more suitable for cattle ranching due to greater rainfall. It could also be that chili cultivation in more humid areas is made less attractive due to a greater prevalence of pests and disease. In the continuous equation, the agricultural income support payments under the PROCAMPO program and years of education are positive and significant. A priori, one might expect years of education to afford more non-farm opportunities and thus carry a negative coefficient.

As can be found in Table 8 for the maize results, in the selector equation, the “under 31” and “full-time non-farm work” both have negative and statistically significant coefficients. Variables for “residence in chili zone,” “residence in central SY,” and the “good soil” variable have positive and statistically significant coefficients. One key finding is that choices regarding labor allocation play a key role in the shape of a household’s agricultural portfolio. With abundant land and very little cash, the family’s labor allocation comes to the fore as perhaps the key choice. Labor constraints drive households toward cattle ranching; from comparison of expected returns, we saw that cattle ranching gives a relatively large return per day of labor invested. Not only does cattle ranching use relatively less labor, it also offers favorable attributes vis-à-vis risk and vulnerability. The activity has also received substantial government support (not reflected in the returns from our simulation given in the table).

Though cattle ranching has many favorable characteristics, chili offers the quickest short-term potential profit on a per hectare basis. Family labor availability is an important determinant of both the decision to undertake the activity and how much is cultivated. The amount of land dedicated to chili is limited by the cash and labor constraints that smallholding farmers face. Labor intensive harvesting means that hired labor is often required. Even as some have abandoned the cultivation of chili, temporarily or permanently—saying the price is too low on average or too volatile—it remains the premier cash crop in the region. If the 2003 harvest had been spared the effects of drought, many would have profited. In contrast, cattle ranching only pays off in the long term.

Generally, maize cultivation is more robust in the face of climatic extremes than chili cultivation, and as the household mostly consumes it, there is no price risk. Also, unlike chili, agrochemicals are not required for maize, and the crop's harvest does not involve repeated, rapid harvesting. Rather, the maize harvest can be achieved steadily over time, making it more manageable with family labor alone. So, maize cultivation is less limited by labor and cash constraints. In addition, there is also a social, cultural component to maize, part of the social norms for some groups. The result of this interplay—of favorable production characteristics (low cash and labor input requirements) and household constraints, risk and diversification concerns, and cultural norms—is that maize is grown to a much greater extent than chili. Across our sample of 174, the average household has more than 3.5 ha of maize and less than ½ hectare of chili.

Taken together, the results demonstrate that resource constraints—labor constraints for all agricultural activities (evident in both econometric results and comparison of returns across land uses), liquidity constraints, and water availability for cattle—are factors in agricultural land use choices consistent with economic theory of optimization under constraints. Evidence of the relevance of the labor constraint is particularly strong—variables relevant to availability of family labor are significant in two of the econometric models, and the comparison of returns across agricultural land uses suggests that, once established, cattle ranching provides the highest profit per day of labor invested for any of the three main activities. On water availability and cattle ranching, note that income can partially substitute for naturally delivered water. More constructed ponds can be dug or existing ones enlarged to extend the availability of wet season water into the dry season, and in extremely dry times, water can be delivered by truck. Thus, rising income would also partly relax water availability constraints on the spread of cattle ranching. The trend of out migration described by Schmook and Radel (2008) reduces the supply of family labor available, thus making even more attractive the relatively low labor demands of cattle ranching. Rising income and continuation or acceleration of out migration would lead to a relaxation of cash constraints and would make labor constraints more restrictive: a formula for continued shift to and expansion of the area devoted to pasture for cattle.

Before concluding, we discuss some of the limitations of our methodology. The economic concept of behavior driven by a constrained optimization decision-making process is one framework for seeking to understand the complicated behavioral process of deforestation on a tropical forest frontier. Other explanatory drivers include: location in space and market access; land tenure; and the broader social and governmental environment; biophysical constraints; population dynamics; technology options; and household preferences, especially issues of risk and vulnerability. Some of these other factors can be incorporated into a theory that land use is driven by a farmer's solution of an optimization problem, for example, the transaction costs associated with spatial location that we have included in our econometric modeling. Gurri (2009) explores another behavioral perspective what economists would call culturally formed preferences. We do not attempt to directly explain cultural effects. We also limit ourselves to allocation choices within the agricultural portfolio, when non-farm economic choices are increasingly relevant. Schmook and Radel (2008) explore the link between migration and the increasing reliance on cattle ranching as an agricultural land use. In this volume, Radel, Row Chowdhury, and Schmook extend this line of reasoning across the spectrum of uses of labor to more broadly consider increasing diversification in income sources, including migration.

Insights into cattle would have been bolstered by investigation into the large operations on privately held lands (ranchos). A particular limitation of the simulation approach to returns to cattle ranching is that it assumes an idealized long-range development process, a rationale year-by-year incremental expansion of pasture and herd size, when the reality on the ground is much less regular and smooth. Our econometric works take a static perspective—uses data from a single year—in an effort to offer insight into what is fundamentally a dynamic process, land use, and its change. Data availability for the region, as in most forest frontiers, is relatively scarce, and far from an idealized panel socioeconomic dataset with repeated observations at regular intervals.

Conclusions

We demonstrate the impact of economic constraints on land use decisions in the SY region using a suite of reinforcing methods. We find that the prominence of pasture in the agricultural portfolio is on the increase in part because of the constraints households face in family labor, one of the household's key resources, and the relatively lower labor requirements of pasture for cattle ranching. Our survey data show a relatively low occurrence of the abandonment of cattle ranching for those who have started and enthusiasm for beginning amongst those who have yet to adopt, which would both support continued expansion of cattle pasture. The results of all three of our approaches are mostly consistent with a priori expectations and are supportive of the meta-hypothesis that constraints on labor, and cash plays important roles in land use decisions, contributing to a hollow frontier.

These results have implications for the potential future development pathways for the SY region, and thus regional environmental change. The spread of pasture suggests a hollow frontier pathway. At the same time, the existence of large areas of former pastures now standing as bracken fern illustrates the potential reversibility of the recent trends related to pasture and cattle. Moreover, the SY region also exhibits the characteristics of a forest transition as is seen in Schmook's (this volume) illumination of an intensification trend in cultivation of crops. Schmook finds the evidence of intensification (defined an increase in cropping frequency, i.e., time spent planted in maize or chili as opposed to time spent as secondary forest) and explains this as result of green policy initiatives on-going in the region, including increasing enforcement of federal prohibitions against cutting old growth forests, as well as because of some attractive features of cultivating anew on secondary forest, including the ease of clearing the land due to smaller tree size and ease of planting due to less compact soil that contains fewer and smaller roots.

Which trend—hollow frontier or forest transition—predominates in the future depends on many factors: the extent to which nascent low income ecotourism can be a broad-based economic development model; whether or not higher value crops—perhaps habanero chili—that require greater inputs, such as irrigation, might be adopted, thus changing the relative attractiveness of cattle ranching; how marketing structures develop in the region, as well as links to markets outside of the region, and changing expectations on the price of maize and beef set in these distant markets. In the end, factors external to the region—Mexican federal government policy, including the success of its archaeo-ecotourism program for the region (Turner this volume), the potential for international interventions such as payments to support reduced tropical deforestation as part of an international framework to address climate change, technology, and market developments (e.g., international commodity prices, and in particular, relative price increases in maize as opposed to cattle)—will be important to the future path of environment and development in the SY region.

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References

Busch C (2006) Deforestation in Mexico's southern Yucatan: recent trends, causes, policy implications. Unpublished doctoral dissertation, University of California, Berkeley

David PA (1969) A contribution to the theory of diffusion. Memorandum no. 71 (Stanford Center for Research in Economic Growth)

Deaton A (1997) The analysis of household surveys: a microeconomic approach to development policy. John Hopkins Press, Baltimore

Defries RS, Asner GP, Houghton R (2004) Trade-offs in land-use decisions: towards a framework for assessing multiple ecosystem responses to land-use change. Geophys Monogr Ser (American Geophysical Union) 153:1–9

Fernandez, JM, Hernández Bahena J (2002) Diagnostico comunitario del ejido Ricardo Payro Jene Municipio de Calakmul Campeche, Mexico. El Colegio de la Frontera Sur: Campeche, México

Geoghegan J, Cotrina Villar S, Klepeis P, Macario Mendoza P, Ogneva-Himmelberger Y, Roy Chowdhury R, Turner BL II, Vance C (2001) Modeling tropical deforestation in the southern Yucatán peninsular region: comparing survey and satellite data. Agric Ecosyst Environ 85:25–46

Goetz JS (1992) A selectivity model of household food marketing behavior in Sub-Saharan Africa. Am J Agric Econ 74:444–452

Gurri FD (2009) Adaptive strategies in migrant peasant households in Calakmul, Campeche, Mexico: preventing family fragmentation amongst agriculturists in areas of low population density (unpublished manuscript)

Heckman J (1979) Sample selection bias as a specification error. Econometric 47:153–161

Just RE, Zilberman D (1983) Stochastic structure, farm size and technology adoption in developing agriculture. Oxf Econ Pap 35:307–328

Key N, Sadoulet E, de Janvry A (2000) Transaction costs and agricultural household supply response. Am J Agric Econ 82(2):245–259

Keys E (2004) Jalapeño pepper cultivation: emergent commercial land use. In: Turner BL, Geoghegan JM, Foster DR (eds) Integrative land change science and tropical deforestation in the southern Yucatán: final frontiers (Clarendon lectures in geography and environmental studies). Oxford University Press, Oxford, pp 207–220

Keys E (2005) Exploring market based development: market intermediaries and farmers in Calakmul, Mexico. Geogr Rev 95(1):24–46

Klepeis P, Vance C (2003) Neoliberal policy and deforestation in Southeastern Mexico: an assessment of the PROCAMPO Program. Economic Geography 79(3):221–240

Manning WG, Duan D, Rogers WH (1987) Monte Carlo evidence on the choice between sample selection and two-part models. J Econom 35:59–82

Mather AS, Needle CL (1998) The forest transition: a theoretical basis. Area 30:117–124

McWilliams B, Zilberman D (1996) Time of technology adoption and learning by using. Econ Innov New Technol 4:139–154

Pichón FJ (1997) Colonist land-allocation decisions, land use, and deforestation in the Ecuadorian Amazon frontier. Economic Development and Cultural Change 44:127–164

Rudel TK, Bates D, Machinguiashi R (2002) A tropical forest transition? Agricultural change, out-migration and secondary forests in the Ecuadorian Amazon. Ann Assoc Am Geogr 92(1):87–102

Sadoulet E, de Janvry A, Benjamin C (1998) Labor market imperfections and selective recursiveness in household models. J Ind Relat 37(1):85–108

Schmook B, Radel C (2008) International labor migration from a tropical development frontier: globalizing households and an incipient forest transition the southern Yucatán case. Human Ecol (forthcoming)

Schneider LC (2006) The effect of land management practices on bracken fern invasion in the region of Calakmul, Mexico. J Lat Am Geogr 5(2):91–107

Tauchmann H (2005) Efficiency of two-step estimators for censored systems of equations: Shonkwiler and Yen reconsidered. Appl Econ 37:367–374

Vance C, Geoghegan J (2004) Modeling the determinants of semi-subsistent and commercial land uses in an agricultural frontier of southern Mexico: a switching regression approach. Int Reg Sci Rev 27:326–347

Vance C, Klepeis P, Schmook B, Keys E (2004) The ejido household: the current agent of change. In: Turner BL, Geoghegan JM, Foster DR (eds) Integrative land change science and tropical deforestation in the southern Yucatán: final frontiers. Oxford University Press, Oxford, pp 171–188 (Clarendon lectures in geography and environmental studies)

Walker R, Perez S, Caldas M, Teixeira Silva LG (2002) Land use and land cover change in forest frontiers: the role of the household life cycles. Int Reg Sci Rev 25(2):169–199