DRAFT
Not For Citation

Technical Note 1.1 – Smallholder Deforestation and Land Use: A Baseline[1]

February 10, 1999

Chantal Line Carpentier[2]

Julie Witcover[3]

Stephen A. Vosti[4]

Abstract

This Technical Note presents the baseline scenario of a farm-level bioeconomic LP model developed to assess the impacts of policy and technology changes on deforestation and land use by smallholders at the margins of the Western Brazilian Amazon, and the income implications of these changes. The structure and initial conditions of the model are explained, and some of the output generated by the model over its 25-year decision time horizon are presented. More specifically, patterns of land and labor use are presented and discussed. Herd dynamics and extractive activities receive special attention, as do farm profits. Implications for forestry and other policies of this baseline simulation are discussed.

This Technical Note is prepared as input into the OED's review of the World Bank's forestry policy, particularly the Brazil case study. This Note is not for quotation or circulation, and its content does not necessarily reflect the views or opinions of the World Bank.

---

[1]This is a numbered Technical Note series, with the potential for particular numbers in the series to have several versions; e.g., Note 1.1 may be followed by an updated presentation of the baseline model, which will be labeled Note 1.2.

[2]Research Fellow, H. A. Wallace Institute. Email address: 104723.2340@compuserve.com

[3]Research Analyst, IFPRI. Email address: j.witcover@cgiar.org

[4]Visiting Research Fellow, IFPRI, author for correspondence. Email address: s.vosti@cgiar.org

Introduction

Responses by resource users to technology and policy changes will determine the effectiveness of such changes. This is true for forestry and other policies that seek to influence deforestation and land use. This series of Technical Notes takes as axiomatic the need to focus on the whole farm, rather than on particular economic activities (in forests, on cleared land, or undertaken in the 'grey' area linking the two). This series also focuses on small-scale agriculturalists at the forest margins, in part because of their sometimes impoverished state (which itself merits policy action), but more importantly because of their critical current and future roles in deforestation. These smallholders are pivotal to slowing deforestation in Brazil; failure to identify new combinations of forestry and other policies, technologies, and institutional arrangements that effectively brake smallholder forest clearing will doom the Amazon.

This Technical Note describes the farm-level bioeconomic linear programming model developed to assess the impacts of policy and/or technological changes on deforestation, land use, and smallholder incomes. A baseline scenario with a planning horizon covering 25 years is presented, and is used to address the following issues. Under current (1993/4) technology, policy, price conditions, will small-scale agriculturists retain any forest at all?[5] Are farmers earning significant profits (and hence improving farm household welfare, perhaps via investments in agriculture on cleared lands) from these projected patterns of deforestation and land use? Are off-farm sources of income important in determining household income and/or land use patterns? What are the major brakes on deforestation at household level? Aside from being of use itself in addressing some policy issues, this baseline also establishes a benchmark as regards deforestation, land use and income generation against which all policy experiments (to appear in future Technical Notes) will be measured.

Several issues arise from this baseline analysis that are relevant for the forestry (and other) policy review. First, if the policy environment does not change, will smallholders continue to deforest, and if so, at what rate? Second, what factors are driving, and braking, deforestation at household level, how strong are they, and what policies might lessen the strength of factors driving deforestation and/or make factors braking it more effective?

The model presented here (and used in all future simulations) was built for the western Brazilian Amazon, and calibrated for those agronomic and economic conditions. Extensive sensitivity analyses were performed and these exercises increase our confidence in the model's ability to predict the impacts of policy and technology changes on deforestation and land use by small-scale agriculturists in the western Amazon, and also strongly suggest that these results (especially the *directions* of farmer responses to policy/technology changes) will be relevant for other frontier areas in the Amazon.

---

[5] This might be viewed as the most conservative possible definition of 'sustainability'.

The next section provides a conceptual sketch of what the model does, and how, sets out the conditions used to 'start' the model, and then presents land use, livestock dynamics, labor use, and other farm-level outputs generated by it. The Note ends with a brief discussion of policy implications of this baseline scenario.

Baseline Simulation

Bioeconomic Model: Linear Programming Model with Biophysical Linkages – A linear programming (LP) model was developed to explicitly account for the biophysical and economic factors determining farmers' deforestation and land use decisions. This bioeconomic model is first used to generate a baseline containing predictions of future land use (and other) decisions based on current technology and policy conditions; that is, to describe the archetypical small-scale farm's patterns of land use over 25 annual production cycles if current conditions persist. Later, simulations are run to assess the impact of changes in technologies and/or policies on deforestation, land use and farm household income.[6] (These will be the foci of future Technical Notes.)

Figure 1 depicts the model's basic structure.[7] The archetypical farmer whose decisions are characterized by the model maximizes the discounted value of his family's consumption stream over a 25-year time horizon by producing combinations of products for home consumption and sale, subject to an array of constraints related to technologies for producing agricultural and extractive products, the impact of agricultural activities on soils, and the financial benefits associated with different activities, including the potential to sell household labor off farm for agricultural purposes.[8] More specifically, farmers know: 1) all relevant production parameters for alternative systems, and the input use and yield implications of alternative ways of producing them; 2) the impacts (most negative, but some positive) on soil nutrient availability of different cropping systems, and the

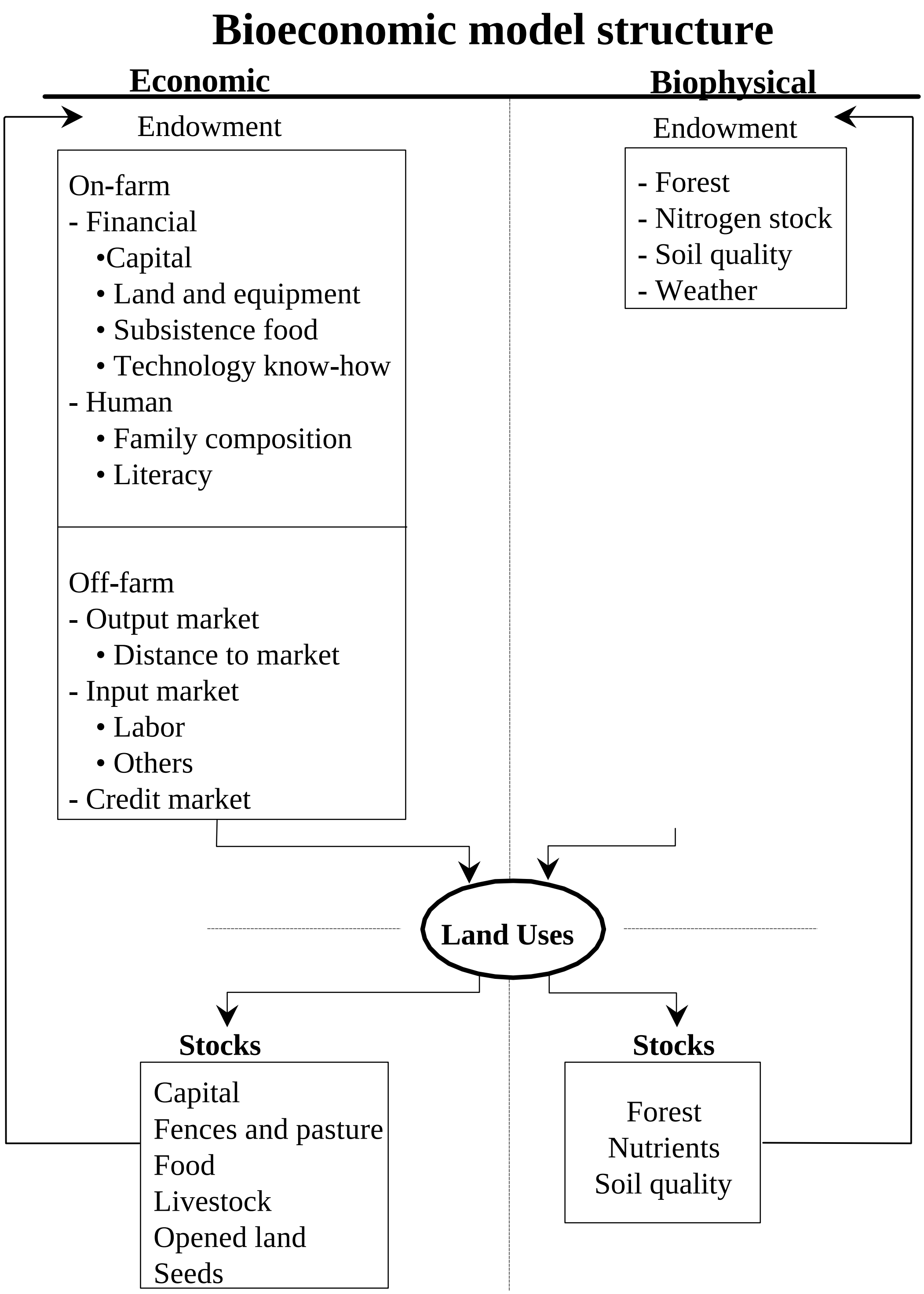
---

[6]Note that some potentially important factors influencing deforestation and use of cleared land have ***not*** been incorporated into this version of the model, most notably: the asset values of different types of land; land tenure; off-farm investments other than family labor hired out; and production risk due to unexpected weather shocks. Asset values will be the focus of future work. Land tenure and income diversification strategies involving non-agricultural activities are addressed in the regression work. We expect the explicit treatment of risks (weather, price, policy and other) to reinforce our results — that is, cattle production systems are dominant in virtually all model experiments, and the inclusion of risk would make these systems even more attractive. In future work, we intent to link the bioeconomic model with the Decision Support System for Agrotechnology Transfer (DSSAT) crop growth model, which contains a weather generator capable of simulating weather shocks and long-term climate change.

[7]A technical description of the model has been sent to members of the Brazil case study team. Those interested in receiving more and more detailed model-related documents can contact Steve Vosti.

[8] After much experimentation, 25-year time horizon was found to contain most of the farm-level adjustments associated with the model stability and policy experimentation simulations presented here. If simulations display important post-25-year adjustments, these are reported.

Figure 1 — Model's basic structure



implications for crop yields of changes in nutrient availability; and c) input and output prices, including costs of labor hired in and returns to family labor hired out.[9]

Figure 2 depicts the various types of uses to which cleared and forested land can be put, and more important, the inherent 'stickiness' associated with land use options. Once land is taken out of forest, it can be used for any production activity. However, if land is put to annual crops, it cannot remain in this activity for more than three years, as yield declines force farmers to switch to fallow or to pasture.

Aside from a set of alternative economic activities (and their associated technical production coefficients), their financial returns, and the biophysical factors that constrain activity choices over time, the model must have a set of initial conditions, that is, an explicit set of farm and farm household characteristics that indicate the model's starting point in terms of land already in use (for example, area in pasture), and farm- and household-specific constraints (for example, family size) that can influence the allocation of land, labor and cash to alternative land uses. Table 1 presents these initial farm and farm household conditions. [10]

As suggested by some elements of Table 1, the archetypical farm on which the LP model is based (for baseline and other simulations in this Technical Note series) does not begin from 'zero,' i.e., the model does not attempt to characterize land use of farm households just arriving at the forest margin and attempting to settle 100% forested lots. Rather, based on a clustering of farms from which micro data were collected, the LP model takes as its point of departure a farm household (with characteristics reported in Table 1) residing on a 58-hectare lot. This lot has been open for about 13 years and already contains approximately 16 hectares of cleared land, about half of which has been dedicated to pasture.[11] The LP model, then, takes this farm household-farm combination as 'year 0' for its baseline scenario.

---

[9]1993/4 market prices were used for the entire 25-year simulation time horizon, i.e., farmers face constant, known relative price ratios over that planning horizon. Simulations using 1996 market prices (which differed substantially vis-a-vis 1993/4 prices, especially as regards milk and coffee prices) yielded somewhat different land use patterns, but deforestation patterns remained about the same; despite more land and labor being dedicated to coffee, farmers left no primary forest in the long term.

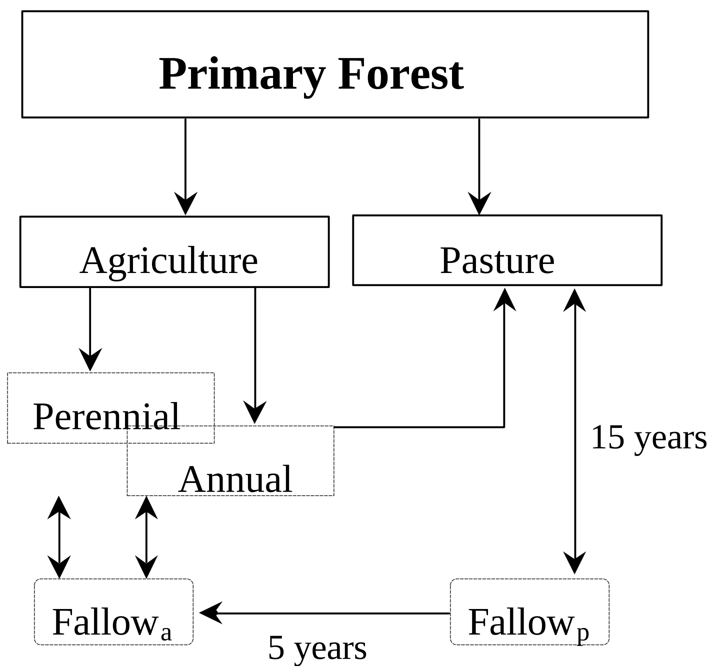
[10] The model's point of departure was determined from field data collected in 1994. Farm households were clustered on the basis of characteristics deemed to be exogenous to farmers (for example, soil type). Several clusters emerged, each of which can be thought to represent a farm type. The average farm and household characteristics for a ***relatively well-situated farm type*** in terms of soil type and access to markets were used to generate the model baseline. All model simulations take as a point of departure the characteristics of one typical farm as identified from the Pedro Peixoto, Acre sample using this cluster analysis.

[11]Visually, this 'starting position' as regards land use is captured at year 'zero' along the horizontal axis of Figure 3, which registers positive amounts of land in forest, pasture, annual crops, perennial crops, and secondary fallow.

Finally, the baseline scenario contains a policy ‘package’ considered appropriate for the western Brazilian Amazon, some elements of which will be the foci of future Technical Notes. First, the 50% rule is not enforced, as there is little evidence that it deters forest clearing on farms. Second, timber extraction is not permitted. Third, no formal credit is available for agricultural investments, though short-term consumption loans are permitted to meet food needs. Finally, some of the most intensive forms of annual crop and livestock production systems (although theoretically available to farmers and quite profitable) are not permitted in the model, since they were not observed during field data collection.

Figure 2 – Generic land uses

Agricultural realities in northern Brazil



Non-renewable Stock

Renewable Stock

Table 1 — Farm and farm household initial conditions for the bioeconomic model

Initial Conditions	Baseline Values of Initial Conditions
<u>Markets, Transactions and Prices</u>[12]	
Labor transactions (max. number of man-days/month)	
hired	15
sold	15
Milk quota (max. liters sold/day)	50
Product price 'wedge' (%)[13]	15
Input price 'wedge' (%)	20
Cattle price 'wedge' (%)	25
Agricultural credit (R$)	0
Technology available[14]	traditional (v1), improved(v2), and modern (v3)
Brazil nut production	
latas/hectare	1
man-days/lata	.05
<u>Transportation</u>	
Transport time (days/round trip to market)	
ox, dry season	1.5
ox, rainy season	2.0
truck, dry season	.63
truck, rainy season	.78
Transport cost (round trip to market)	
truck (R$)	91
<u>Household Assets, Liquidity, Expenses</u>	
Food storage capacity (kg)	2000
Minimum near cash maintained (R$/season)	500
Initial cash balance (R$ in year 1)	250
Minimum expenses (R$/month)	118
Initial cleared land (hectares)	17
Adult male laborers	1.63
Other family laborers (adult male equivalents)	1.47

[12] Unless otherwise stated, all prices are reported in terms of 1996 Brazilian reais.

[13] Farmers cannot buy and sell particular commodities, inputs or livestock at the same price in the marketplace; limited volume, market links, and product quality issues usually establish a 'wedge' between product sale and purchase prices. These price 'wedges' were estimated from field information, and are included in the model as initial conditions and maintained throughout.

[14] For a detailed description of production technologies, see the technical description of the model distributed earlier, or contact Steve Vosti.

Model Baseline[15] – What will be the resource use strategies adopted by the archetypical household over a 25-year time horizon? More importantly, will the land use patterns that emerge be sustainable, by one definition or another? To address these issues, we examine some of the output generated by the farm-level bioeconomic model, focusing particularly on three sets of indicators: land uses (implicitly including deforestation) and economic activities, labor uses, and farm profits.[16]

Figure 3 depicts land uses (including forest, and therefore implicitly deforestation) generated by the model for a 25-year time span for a typical small-scale farm.[17] Several results emerge from this baseline. First, the amount of forest retained is clearly declining over time, finally disappearing in about year 25, despite the small but positive revenue provided by the extraction of Brazil nuts (an activity currently undertaken by about 50% of sample farms). Second, in terms of area, cattle production is the dominant activity and pasture to support it eventually occupies about 85% of the farm. Third, annual crop production occupies about 8% of the farm throughout the 25-year time horizon. Finally, perennial tree crops (in this case, manioc, which has production cycle spanning more than one year) takes up about a hectare of land over time, and secondary fallow weaves into and out of the baseline land use scenario, becoming significant as forests disappear completely.[18] Note that no degraded pastures appear in Figure 3, indicating that the archetypical farmer manages his pastures under *this* baseline policy/technology scenario so as not to degrade them. In other scenarios, this is not the case.

---

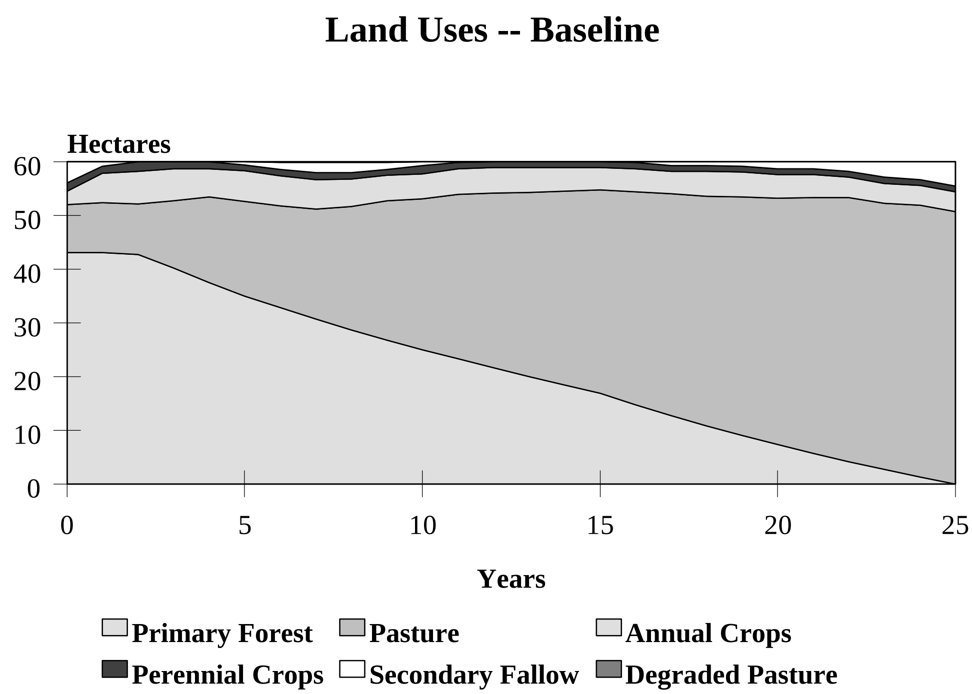
[15] This Technical Note setting out baseline results contains diagrams and discussions (for example, labor hired in and cattle herd dynamics) that, to save space, will not be replicated in other Technical Notes focusing on simulating policy experiments. Where relevant, these issues will be addressed.

[16] In addition to the diagram presented here, the LP program generates information on yearly total crop produced, consumed, kept in stock and sold, grains and beans bought for consumption and to use as seeds, nitrogen in the cultivated and forested area, nitrogen deficiencies in cultivated areas, equipment stock at any time and equipment bought per year, and transportation means and months to bring crop sold to the market.

[17] Again, the model begins with a lot that has been open for about 13 years, so ‘year’ along the horizontal axis of Figure 3 and the remaining figures in this Note represents an annual cycle completed by the LP model beginning from that point.

[18] Baseline simulations out to 35 years suggest that the area in secondary fallow continues to increase at approximately .20 ha every 2 years to reach 5.5 hectares in year 35.

Figure 3 – Baseline land uses, by year

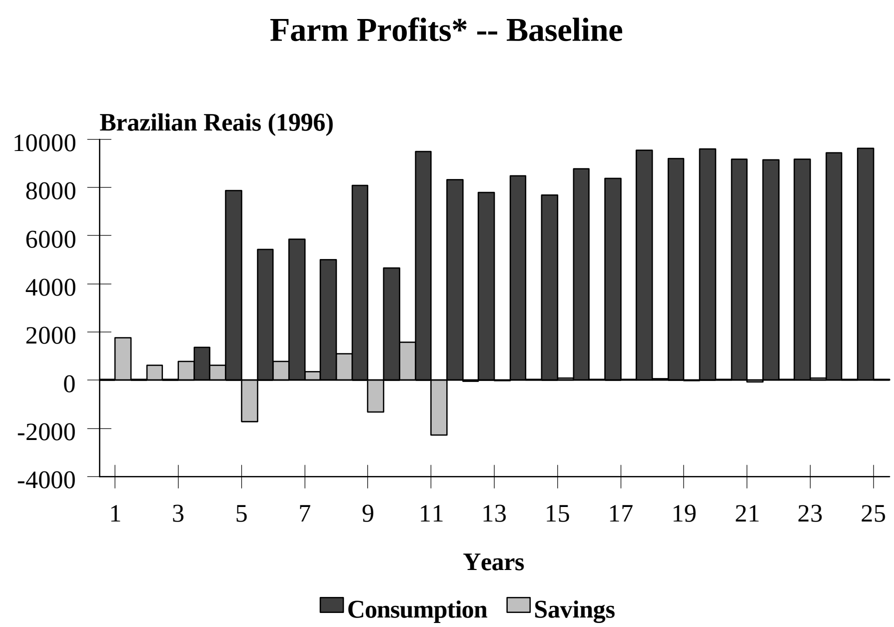


Farm profits (consumption plus savings; the latter can be negative) are reported in Figure 4.[19] Savings during the first few years allow for subsequent investments that boost consumption in later years. Large investments (negative savings) are required in years 5, 9, and 11 to expand pasture areas. Profits plateau at about year 13, at a level of approximately R$9,000 per year. [20]

[19] Note that farm profits are net of the cash value of basic food needs and cash required for minimal living expenses.

[20] Minimum consumption in the model is determined by food habits and household size. Farm households were asked how much they spend per month on fixed expenditures such as sugar, salt, cooking oil, clothes, hoes, etc. The sample was broken down by household size and wealth. Households are required to have on hand sufficient food (either in-kind or in cash to purchase it) to feed family members each season. Borrowing is allowed, but must be repaid by the end of the calendar year in which the consumption loan is taken out.

Figure 4 – Farm profits, by year



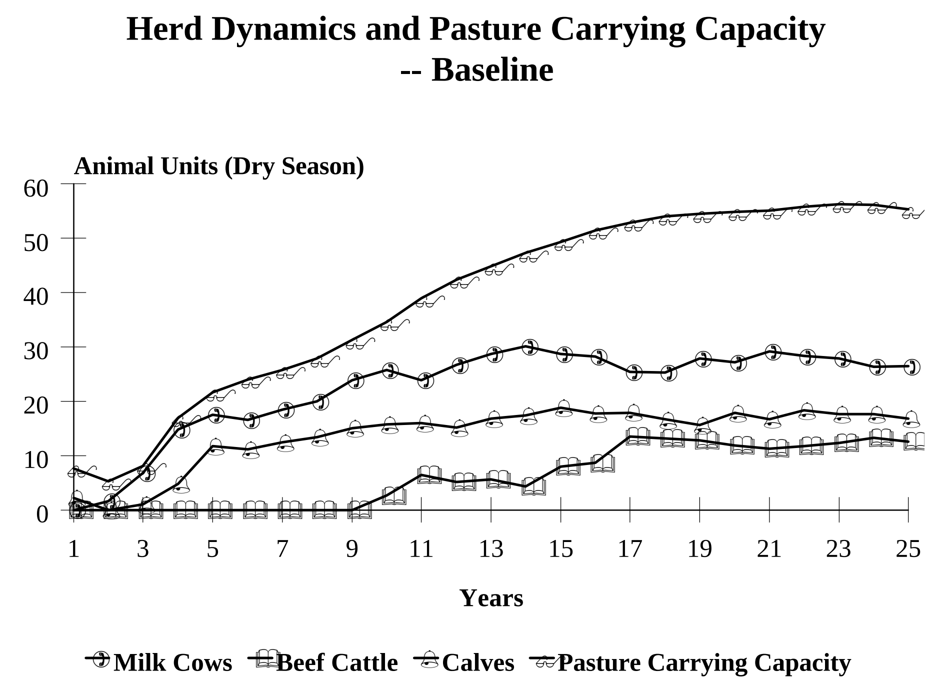
*** Profit = consumption + savings; savings can be negative.**

The dominance of pasture on the archetypical farm merits a closer look. Figure 5 depicts three types of cattle (milk cows, beef cattle and calves, in animal units), and the total pasture available for maintaining the herd at different points in time.[21] Two issues emerge. First, dairy production begins early on in the 25-year scenario, and continues to play an important role throughout — once the milking herd is established (say, by year 10) roughly 77% of income is derived from dairy operations, which occupy 42% of available household labor, averaged over the months with the exception of May. In May, pasture and animal care account for 128% of available household labor, implying that 15 man-days (the maximum allowed by the model) must be hired in May. Second, beef cattle production emerges as a second cattle activity in year 9, and it's contribution to income peaks in year 18 at which time it represents 25% of household income, but occupies just 4% of available household labor.

[21] The conversion of 'heads' to animal units (AU) is as follows: calf = 0.25 AU, heifer = 0.5 AU, cow = 1.0 AU, bull = 1.25 AU, and an ox = 1.5 AU (EMATER and EMBRAPA 1980). The bioeconomic model contains 3 levels of pasture management technology: level 1 permits quick degrading, level 2 permits slow degrading, and level 3 does not permit reductions in pasture carrying capacity. Farmers choose pasture management technologies.

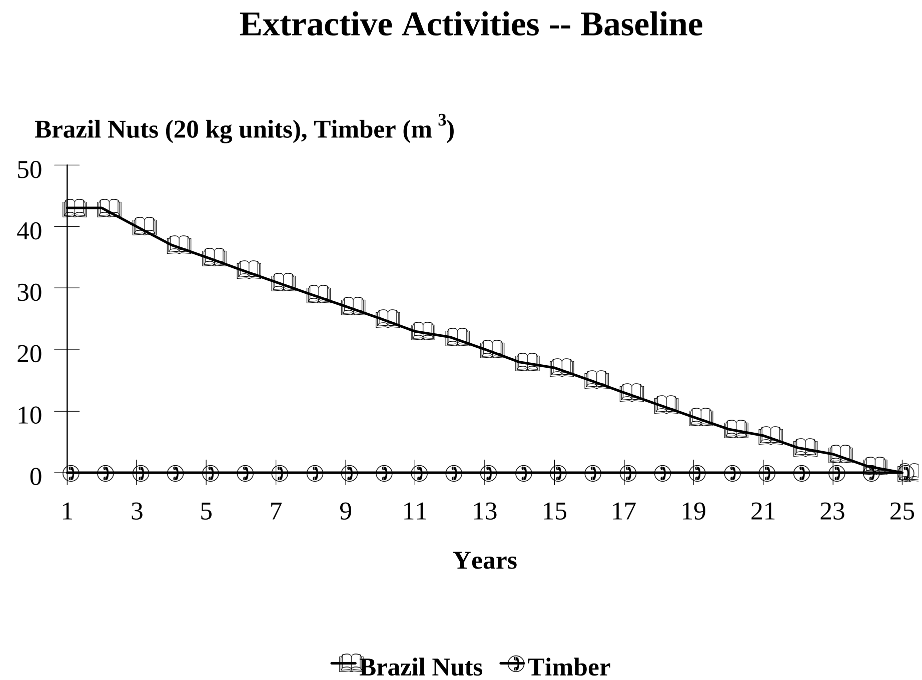
Extractive activities are a diminishing source of income to smallholders in the baseline run.[22] Figure 6 depicts this steady decline in extractive activities.

Figure 5 – Livestock activities



[22] The supply of Brazil nuts is directly linked to the amount of forest cover remaining on farms. The same survey data from 1994 used to identify farm types were also used to estimate Brazil nut off-take. Timber off-take, which also appears in Figure 6, is zero in the baseline scenario, by policy design. This constraint will be relaxed in future Technical Notes.

Figure 6 – Extractive Activities



Labor has emerged as a critical determinant of land use and deforestation. Unlimited labor supply (at 1993/4 wages rates of R$7.00 per day) means quick and complete deforestation. But labor markets are not perfect in these remote areas, so households generally cannot hire as much labor as they might choose to and can afford. For the baseline, the maximum amount of labor that a given household can hire in in any given month is 15 man-days.[23] The same monthly limit is applied to man-days of family labor that can be hired out.[24] Figures 7 and 8 depict monthly labor purchases and sales, respectively, by month for the 25-year baseline scenario. Labor purchases in May for deforestation, fence construction and maintenance almost always reach the established limit. Labor purchases in February and April often reach the 15 man-days per month limit, too.

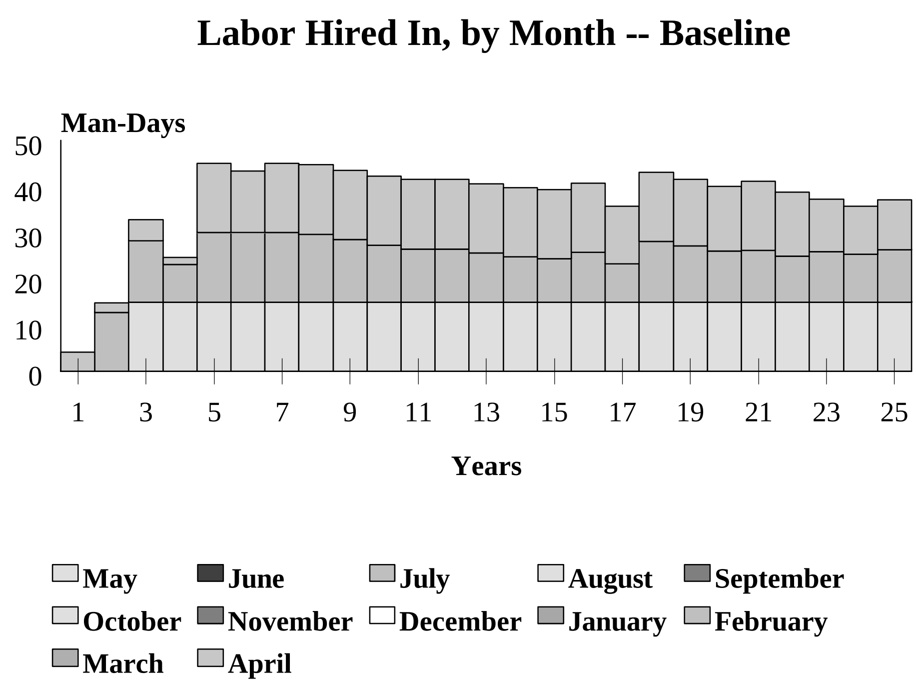
---

[23] This limit on labor that can be hired in was established from fieldwork. Note that deforestation rates are very sensitive to constraints on hired in labor; this issue in addressed below. Note also that deforestation rates are *not* particularly sensitive to constraints on the hiring out of family labor; however, household *incomes* do vary substantially if this constraint is changed.

[24] Note that labor can be hired in and hired out simultaneously in a given month, and that only adult male labor is allowed to be hired in or hired out.

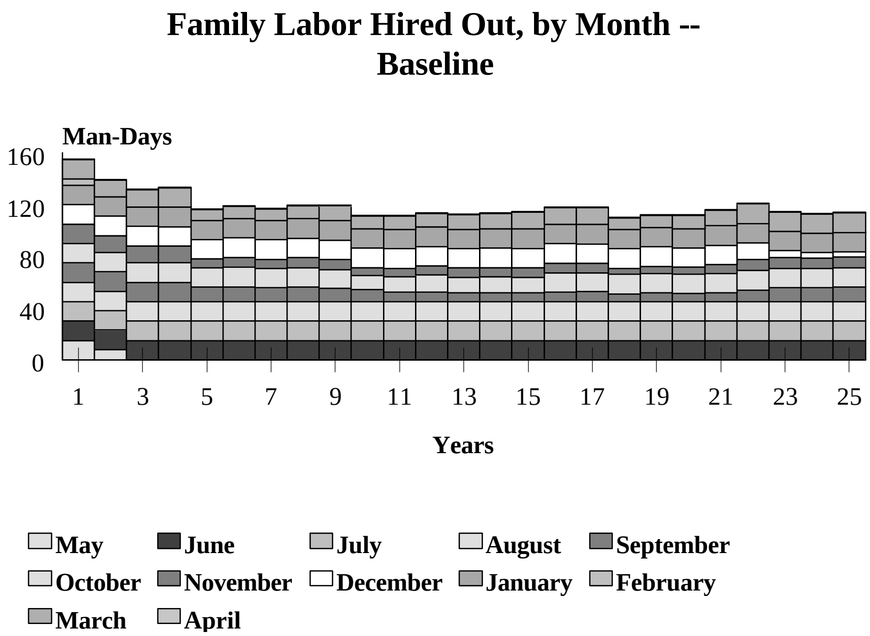
The model suggests that household will generally take maximum advantage of off-farm labor opportunities, almost regardless of season.[25] Indeed, as Figure 8

Figure 7 – Hired labor, by months and year



[25] Wages vary seasonally in the model: during peak season months (May and June), daily hired labor receives R$7 per day; relatively high labor months (March and April) receives R$5.6 per day, and off-peak months receive R$3.7 per day. Note also that a 12.5% wedge per day is applied between hired and sold labor on farm, in part to reflect supervisory responsibilities generally required when labor is hired on farm. While the model does not assign value to leisure time (thereby inducing sales of idle household labor whenever possible to increase income), it does restrict the number of hours per day and the number of days per week that household members can work (i.e., the model forces household members to 'rest' at times).

Figure 8 – Labor hired out, by month and by year

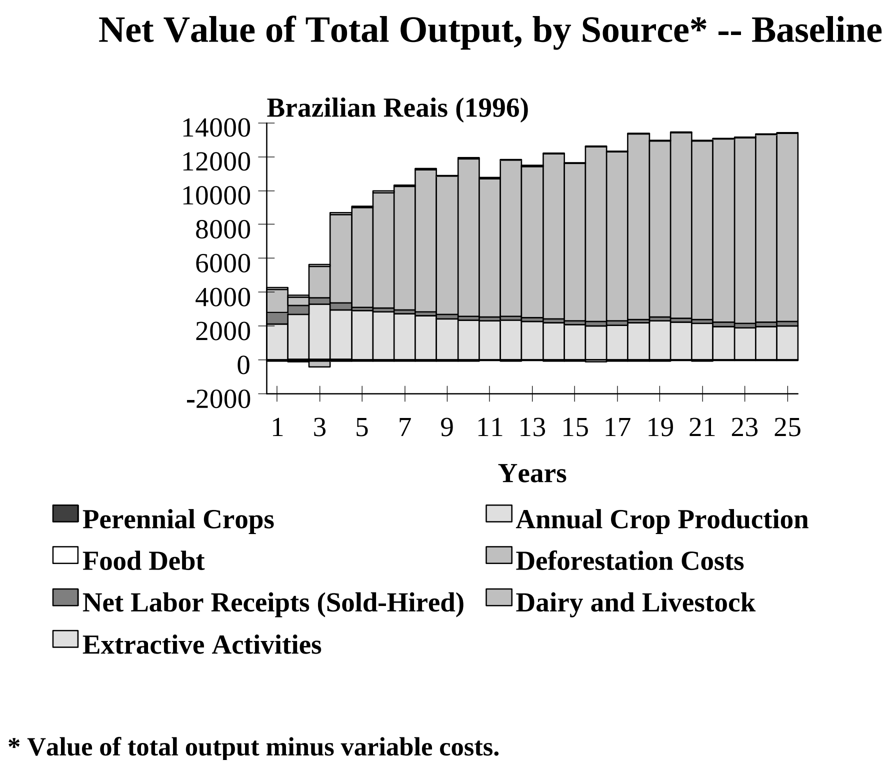


suggests, during June, July and August, household sell as much labor as they are allowed. Labor is never sold off farm in February, May or April, and depending on the year of the simulation period, some labor is sold in the remaining months, but not up to the established limit.

Finally, the model generates the financial returns associated with selected economic activities. Figure 9 depicts the net value of total output (VTO), by source, for each year. As expected, dairy and livestock activities contribute the majority of this measure of income beginning in about year 4, with labor contributing a fairly constant absolute amount throughout the simulation period. Note also that net labor receipts (value of labor sold minus the value of labor hired in) contribute a fairly important share during the first couple of years, and remain constant (but small) thereafter. The net present value (NPV) of this 25-year VTO stream is R$50,635.[26]

[26] A discount rate of 9% was used to calculate the NPV.

Figure 9 – Farm Profits, by year and source



Conclusions and Implications for Forestry (and Other) Policy

Some conclusions emerge from this baseline that are relevant for forestry and other policies in Brazil.

First, as regards the overall sustainability of small-scale agriculture, the baseline suggests that the farming systems characterized by the model and confronting this policy/price/technology scenario will be completely deforested in about 25 years. Therefore, this archetypical farm will *fail* any test of sustainability that requires that some area remain in primary forest. However, this farm contains combinations of agricultural, extractive and off-farm activities that *do* sustain livelihoods, as demonstrated by the increased and sustained flows of income they generate.

Second, the deforestation and land use patterns generated by the baseline scenario are *highly* sensitive to labor availability (but somewhat surprisingly, not to wage rates). If farm households had access to all the labor they desired (and could afford to hire), deforestation would be much quicker than that suggested by the baseline. In a sense, then, labor market imperfections (witnessed during fieldwork and injected into the LP model in the form of limits to monthly flows of labor, onto and off of farms) are a brake on deforestation and put downward pressure on household income. As regards deforestation, labor constraints are most critical during the months of May and June, during which most felling of forest is done in the western Amazon. Policy or other actions that eased labor constraints during that time of the year would likely increase deforestation.[27]

Third, deforestation rates are also sensitive to some of the model's initial conditions, but not to others. For example, farmers with greater initial cash balances (available for hiring labor) deforest much faster than cash-constrained farmers. But, while farmers with poorer soils (the focus of a future Technical Note) have somewhat slower deforestation rates than those with good soils, the end result (complete deforestation) is the same in both cases; however, incomes of farmers with good soils are much higher than those with poor soils.

Fourth, there are several important forestry and other policies contained in the baseline policy 'package' that merit mention. First, the baseline policy package eliminates the 50% rule for smallholders. Second, the policy package *prohibits* the off-take of timber products (sustainably or otherwise), thereby dramatically reducing the potential value of standing forest to smallholders. Third, no agricultural credit is available to the archetypical farm, so although farm households can

---

[27] In other parts of the Amazon, the timing of forest felling is different, and the 'window' for felling might be longer or shorter. We expect larger 'windows' for forest felling to increase deforestation. However, 'moving' the forest felling window along the agricultural calendar can increase or decrease deforestation rates, depending on the degree of labor competition. For example, in Acre, the forest felling period overlaps with the periods for pasture establishment and maintenance, and the establishment of fences. Therefore, 'moving' the deforestation window (say) towards July/August would reduce competition for labor on farms, and likely increase deforestation.

borrow to cover food needs, they cannot borrow to invest in agriculture. Fourth, market prices are used for all inputs and outputs, i.e., policymakers do not intervene directly in setting the model's prices. The impact on deforestation, land use and incomes of these and other policies will be the bases for 'what if' scenarios examined in future Technical Notes.

Finally, average annual farm profits (about R$6,000) are high, indeed, several times 1995 per capita GDP for the country as a whole, which was approximately $3,640.[28] This suggests that even in the relatively unsubsidized policy environment of the mid-1990s, financial incentives exist for interregional migration to establish small-scale agricultural enterprises.[29] Establishment of new roads and the expansion of colonization efforts would help induce such migratory flows.

---

[28] In 1996, the Brazilian real was worth about US$1 (World Development Report 1997).

[29] To confirm these financial incentives, migration costs and the cost of establishing small-scale enterprises (land purchases and other establishment costs, for example) would have to be considered.