**Learning about an old technology: fallow-based agriculture in Brazilian Amazon**

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**Resumo**

Nos sistemas agrícolas baseados em pousio (ABP), o fator de uso da terra ótimo é determinado pelo *trade-off* entre a ociosidade da terra e fertilização gratuita. A hipótese de conhecimento perfeito acerca da relação entre o fator de uso da terra e o rendimento é relaxada, sendo substituída pela hipótese de que os agentes tendem a desviar-se do ótimo em uma magnitude que decai com o conhecimento sobre a ABP. Nesse quadro, o aprendizado sobre a ABP importa. É proposto um modelo empírico para testar a hipótese de que *proxies* para o conhecimento são previsores estatisticamente significativos da variação do fator de uso da terra efetivo. A hipótese é não refutada por microdados no nível do estabelecimento agropecuário referentes a três municípios do Estado do Pará, Amazônia brasileira. E isso mesmo controlando por fatores que determinam o nível ótimo do fator de uso da terra. O que pode ser interpretado como uma evidência de que a terra está sendo sub ou sobre utilizada, devido à falta de conhecimento adequado acerca da agronomia da ABP. Adicionalmente, o artigo contribui para a pesquisa científica em agricultura sustentável ao propor um arcabouço para o estudo do processo de aprendizado de práticas de manejo de sistemas agrícolas e florestais.

**Palavras-chave: pousio, aprendizado, Amazônia**

**Abstract**

In fallow-based agriculture (FBA), the optimal land use factor is determined by the trade-off between land idleness and cost-free fertilization. The hypothesis of perfect knowledge regarding the relation between the land use factor and yield is relaxed, being replaced by the assumption that agents tend to deviate from the optimal in a magnitude that decreases with the knowledge about FBA. In such framework, learning about FBA matters. An empirical model is proposed to test the hypothesis that proxies for knowledge are statistically significant predictors of the cross-sectional variation of effective land use factor. The hypothesis is not refuted by farm-level data, gathered from a survey conducted in three municipalities of Pará state, Brazilian Amazon, even controlling by factors that determine the optimal level of the land use factor. What can be interpreted as an evidence that land is being under or over utilized, one of the reasons for this being the lack of precise knowledge regarding the basic agronomics of FBA. Additionally, the paper contributes for scientific research in sustainable agriculture by proposing a framework for the study of the process of learning about the management of agricultural and forest systems.

**Keywords: fallow, learning, Amazon**

**JEL Codes: Q12, D83, C21**

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1. **Introduction**

The seminal papers of Arrow (1962), Becker (1994 [1964]) and Romer (1986) motivated the introduction of the study of the implications knowledge accumulation, and also of the mechanisms of learning, in the research agenda of development economics (Arifovic & Karaivanov: 2010, p.1968).

The modern literature on the econometrics of learning (Cameron: 1999, Foster & Rosenzweig: 1995, Conley & Udry: 2010, just to mention a few) is focused on evidencing the channels through which knowledge about agricultural techniques influences productive decisions of farmers located on developing countries. Such channels can be classified in two big categories, individual learning and social learning. The former refers to experiments conducted independently by agents, where new agricultural techniques or new possibilities for old practices are tested (and “firsthand” information is generated, Moscarini & Ottaviani: 1995). The latter consists in observing other agents experimenting with new techniques/practices and generating results that are publicly observable but generally with some noise (the case of “secondhand” information, Moscarini & Ottaviani: 1995). It is social learning that gives places to knowledge spills-over (Conley & Udry: 2005, Bikhchandani et al: 1992, Thornton & Thompson: 2001).

The paper, inspired by the recent empirical research on learning, lays on a survey of Brazilian Amazon farmers, to seek evidences that individual trajectories of learning influences how farmers manage secondary vegetation as a source of nutrients for growing annual crops.

More precisely, the management variable focused is the particular ratio in which the land allocated to annual crops is divided between cropping and fallowing, the last one representing a state of idleness where secondary vegetation is left free to grow and retake the land. To refer to the agricultural systems that lay on fallowing the term “fallow-based agriculture” (FBA) [[1]](#footnote-1) is employed in what follows.

At first glance, focusing on an ancient practice, such as fallowing (Mazoyer & Roudart: 2006, chap.3), is a departure from the literature on learning, given its focus on the introduction of new techniques, such as high-yielding seed varieties (HYV) and fertilizers for cash-strapped farmers (Cameron: 1999, Conley & Udry: 2010). Two facts call for a revision of this summary judgment. First, “new” can mean any practice whose performance is a priori unknown or precariously known by farmers. Second, even practices that have being employed by mankind for a considerable amount of time can be the object of learning for specific human groups. Especially when (1) their performance is sensitive to biophysical features, what it is the case of FBA, an agricultural system whose yield depends overall on the amount of nutrients provided by the conversion of secondary vegetation, generally through fire (Angelsen: 1994, Kato et al: 1999); (2) the human groups are immigrants arising from regions with considerably distinct biophysical features, as it is the case of most of the families of non-indigenous farmers located in Brazilian Amazon (Andersen et al: 2002, table 2.2, p.38 and p.35-36).

The paper by Mertz and coauthors (Mertz et al: 2008) make clear that the agronomics of FBA is still not completely understood even by science, specifically in what refers to the precise relation between fallow duration and yield. Authors such as Kato et al (1999), Metzger (2002) and Coomes et al (2011) sustain that Amazonian farmers tend to practice fallow durations that are inconsistent with a sustainable level of yield, what creates a poverty-trap where soil quality and the income extracted from land tend to decay progressively, and consequently, farmers’ standard of living ‑ what Coomes et al (2011) call short-fallow trap. Whether this is led by credit or capital constraints or by the lack of knowledge about the sustainable level of fallow is an open question that has not yet being submitted to empirical refutation.

Evidences of learning about the yield returned by specific fallow durations, among FBA practitioners of Brazilian Amazon, were found by Scatena et al (1996, p.35)[[2]](#footnote-2). The experience in “Amazonian Agriculture” is a part of the forces that drives the household life cycles model employed by Perz & Walker (2002). It is incorporated, through the proxy of duration of residence[[3]](#footnote-3), in the empirical model used by Perz (2003, table III) to explain the variation, within a sample of farmers, of the frequency of pasture burns. Frequency of burns, in the specific modality of FBA known as slash-and-burn agriculture (S&BA), is closely linked with fallow duration, since the fallow can be seen as the timespan between two consecutive burns. The author also incorporates it to other models that explain the adoption of new technologies (chainsaws, pesticides and fertilizers). Coomes et al (2005, p.115) incorporates duration of residence as an explanatory variable for fallow duration and other measures of fallow management. According to the author, the independent variable is a measure for, among other factors, “(…) depth of local environmental knowledge” and “(…) experience with fallowing.”

The influence on the choices of households engaged in FBA of the scarcity of production factors faced, especially of labor, inputs and credit is emphasized by literature (Coomes et al: 2005, Tomich et al: 1998, Vosti & Witcover: 1996, p.1, Palm et al: 2005, cap.1 e cap.18, Nepstad et al: 2001, p.2, Denich et al: 2004 e 2005, Börner et al: 2007, Sorrensen: 2009). But accumulated knowledge has not yet being taken into account. This paper aims to fill this gap, by bringing insights from the literature on the economics of learning to understand how Brazilian Amazon farmers manage fallow. The question to be answered is: are there evidences that observable proxies of knowledge about the agronomics of FBA do explain how the ratio of cropping and fallowing varies across a sample of farmers?

Next section presents the theoretical model in basis of which the empirical model is derived. Third section introduces the data and discusses the construction of measures for learning. Forth section presents and discusses estimation results. A brief conclusion follows.

**3 Theoretical model**

**3.1 Optimal land use factor**

The goal of a farmer that practices FBA can be enunciated as:

Max(γ, x, z) {π(γ, x ,z) = γ[pf(x,z) – wq – cz]}

s.t.

Where π(.) is the average profit per hectare of farm land allocated to annual crops. Such magnitude is assumed to be a function of (i) the share of farm land annually cropped, 𝛾, also known as the land use factor[[4]](#footnote-4), (ii) the input of limiting-factor nutrient, x and, (iii) the input of labor, z. Constraint (a) expresses the fact that nutrients comes from two main sources, the conversion of secondary vegetation, s, and chemical or organic fertilizers, q. The amount of nutrients from the first source, as constraint (b) shows, is regulated by fallow duration, F, and also by local biophysical features, subsumed to the vector Ω, such as the level of humidity, temperature, soil quality and also by the peculiarities of the method of conversion (fire, mulching or manual slashing).

The land use factor, 𝛾, generally omitted from microeconomic models of agricultural firms, is a peculiarity of FBA, a system where the land cyclically shifts from the state where it is cropped to the state where it is fallowed. The duration of each of these two states is, respectively, given by 1 and F, as established by constraint (c).

This last constraint is equivalent to the hypothesis of perfect rotation, what means that the FBA farmer practices a fallow duration compatible, given the total size of the land, with the chosen fraction of the land to be cropped.

Fallow is a period of idleness, during which land generates no income (Klemick: 2011, p. 103), but accumulates nutrients through rainfall deposition into the vegetation that grows spontaneously. The trade-off between the opportunity cost of land and the cost-free fertilization (Angelsen: 1994, p.1) determines the optimal fallow duration[[5]](#footnote-5).

By assuming that agents choose directly the fraction of land to be cropped (𝛾), and not fallow duration (F)[[6]](#footnote-6), the theoretical model projects such trade-off in space[[7]](#footnote-7). It postulates that the optimal land use factor is the one for which a further marginal increase would yield an expansion of the cropped area below the necessary to compensate the reduction of the average yield per cropped hectare imposed by the lower input if nutrients from fallow. A formal statement of such principle is presented in what follows.

(Step 1) From the third constraint, it is possible to write: . What leads to the principle that F decays with the rise in the land use factor[[8]](#footnote-8).

(Step 2) Under the light of the first step, constraint (b) becomes: .

(Step 3) By plugging the constraints, it is possible to rewrite agent’s problem as:

Max(γ, q, z) {v(𝛾) [ph(γ,q, z; Ω) –wq – cz] = v(𝛾) }

Where v(𝛾) = 𝛾 and h(γ,q, z; Ω) = f(g(γ;Ω)+q, z). The function h(.) gives the average yield on a kg per hectare basis, considering, on its denominator, only the area annually cropped. The land use factor influences such magnitude only through the channel of fallow duration (steps 1 and 2).

(Step 4) The first order condition, in respect to 𝛾, is:

The RHS is the measure for the benefit of an increase in the land use factor: it gives the increase in total profits coming from the extension of the area annually cropped, under the assumption that the average yield on the area cropped, h(.), does not change. The LHS captures the cost of an increase in the land use factor, once it represents the reduction in the average yield, h(.), imposed by fallow shortening. The optimal land use factor is the one that perfectly balances the benefit and the cost just discussed.

**3.2 The role of knowledge**

Farmers can only reach the optimal land use factor whether they precisely know the average yield function, h(.). The theoretical model implicitly assumes this.

However, the evidence about the practice, by Amazonian farmers engaged in FBA, of unsustainable fallow durations, from the agronomic point of view (Coomes et al: 2012, Kato et al: 1999, Comte 2012), suggests that relevant drivers of the choice of the land use factor may be overlooked if the hypothesis of perfect knowledge is *a priori* assumed[[9]](#footnote-9).

For this reason, the hypothesis of perfect knowledge is relaxed, being replaced by the assumption that agents tend to deviate from the optimal land use factor and the absolute magnitude of such deviations is a decreasing function of the amount of relevant knowledge accumulated.

Formally, let the optimal land use factor be represented by 𝛾\*. Owing to knowledge limitations, the land use factor observed in practice, 𝛾o, might divert from 𝛾\*, i.e., 𝛾o – 𝛾\* = ∈≠ 0. The absolute value of the discrepancy, , decreases with the amount of knowledge about function h(.), accumulated by the farmer, which will be indicated by the letter K. This hypothesis is non-refutable, since, under its validity, 𝛾\* is non-observable, but is in line with the literature on learning ‑ see, for instance, the theoretical models of Foster & Rozensweig (1995), Cameron (1999) and Conley & Udry (2010) – it is, in fact, a hypothesis very similar to the one that basis the input-target model adopted by Goodwin et al (2002).

Therefore, the observed land use factor varies, across farmers, not only with the factors that determine its optimal value, i.e., the parameters of the agent’s problem (p, c, w, T and the vector Ω), but also with the amount of knowledge accumulated, K, i.e.:

𝛾o = 𝛾\*(p, c, w, T; Ω) + ∈(K)

Knowledge, for its turn, can be built through formal instruction (on agronomics/ agricultural practices), observation of experiments conducted by others or from experiments independently conducted by the agent. As table below suggests, the latter possibility seems to fit better the reality of the sampled farmers. Considering the learning of land clearing and land management techniques, around 60% of the interviewees declared to have laid solely on self-experience or family experience.

**Table 1 Sources from which interviewees have learned land clearing and land management techniques**

|  |  |  |
| --- | --- | --- |
| **Learning source** | **Count** | **Percent** |
| Self-experience or family, only | 99 | 63% |
| Formal instructiona and/or other sources except neighbors and colleagues | 32 | 21% |
| Neighbors and colleagues and/or other sources except formal instruction | 9 | 6% |
| Other sources except formal instruction, neighbors and colleaguesb | 16 | 10% |
| **Total** | **156** | **100%** |

aCourses or technical assistance; bRadio, television, internet and labor unions.

Source: RASDB (see section 4.1 below).

Experiments where the land use factor is changed and the resulting yield (and, consequently, profit) is observed seems to be the main method adopted by sampled farmers to build knowledge about function h(.).

In fact, from a purely theoretical standpoint, the optimal level of 𝛾 can be discovered by agents through trial-and-error[[10]](#footnote-10), assuming that z, q and the parameters p, w, c and Ω remain unchanged during experiments and also that π(𝛾, q, z; Ω) = v(𝛾) is concave in 𝛾. Simple rules-of-thumb would do the job, such as “if an increase in 𝛾 results in a higher profit, increase 𝛾 further, contrariwise, do not increase 𝛾”[[11]](#footnote-11). Figures 1.a, 1.b and 1.c below illustrate how the quality of the result, i.e., the difference between the optimal level indicated by the trial-and-error procedure, point “A”, and the true optimal level, depends on the number of trials.

The data available has no information for testing the hypothesis that farmers engage in trial-and-error procedures aiming to find maybe not necessarily the best level for the land use factor, but a better or satisficing[[12]](#footnote-12) level. Nevertheless, once this hypothesis is assumed, the data can be used to test whether past changes on the land use factor, conducted by farmers, are correlated with the present level of the land use factor[[13]](#footnote-13).

**4 Empirical model and data**

By adding an error term, u, to the equation that results from the theoretical model and also assuming that all explanatory factors have a linear relation with 𝛾\*, one has:

𝛾o = 𝛽0+ 𝛽1p+ 𝛽2c+ 𝛽3w + 𝛽4T+ 𝛽5Ω + 𝛽6K + u

Owing to data limitations, further simplifications must be introduced in order to make the model estimable. The details are in the next subsections.

**4.1 The Sustainable Amazon Network survey database**

The "Sustainable Amazon Network " (RAS, in its acronym in Portuguese), started in mid-2009 and gathers around thirty institutions, among them, the Universities of Cambridge (UK), Lancaster (UK), Campinas (Unicamp), São Paulo State (USP), Pará State (UFPA), the Pará State Emílio Goeldi Museum (MPEG) and the Brazilian Agricultural Research Corporation (EMBRAPA). It is a multidisciplinary research initiative with the objective of assessing the sustainability of land use / natural resource management systems, located in the Brazilian Amazon (Gardner et al: 2013).

**Figure 1.a two trials**



**Figure 1.b four trials**



**Figure 1.c six trials**



In its first phase, finished in 2011, primary biophysical and socioeconomic data were generated from field collection. A stratified sampling approach was chosen, in which each strata coincides with a microwatershed (34 in total) and representativeness is sought in such level. For this, interviews were conducted in two regions, the first one being composed by the contiguous municipalities of Santarém and Belterra (both in western Pará) and the second one only by the municipality of Paragominas (Southeast of Pará), figure 2 below.

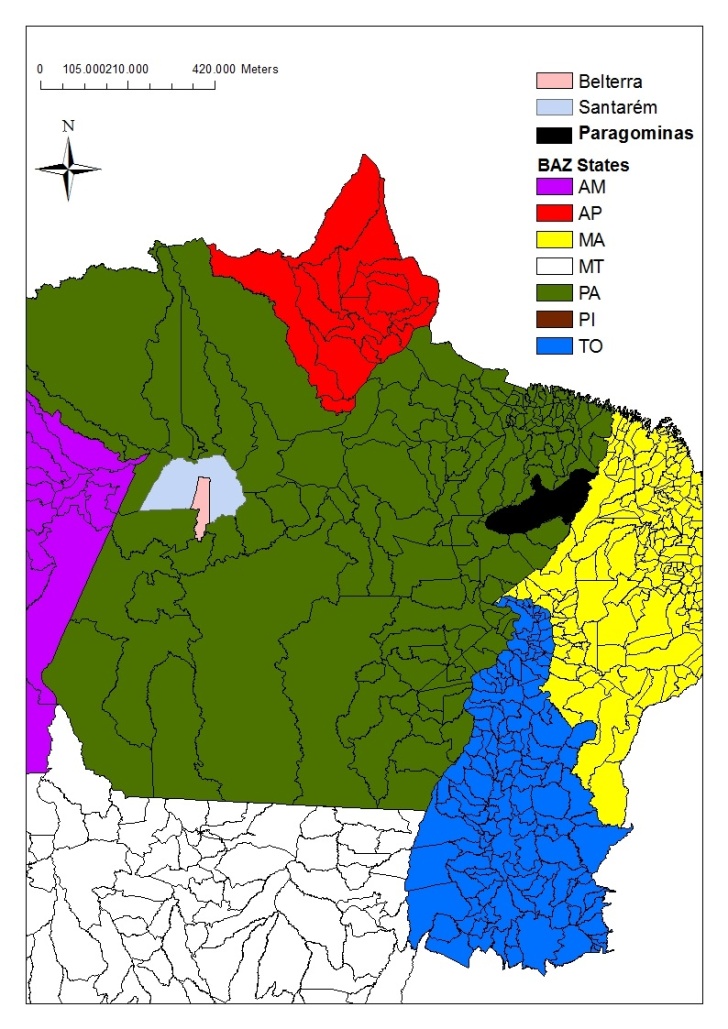
A structured socioeconomic questionnaire was applied to 488 farms or rented farm parcels located on the municipalites of Santarém, Belterra and Paragominas (state of Pará, Brazilian Amazon). The interviews covered aspects related to welfare, livelihood, demography and agriculture.

Farms were sampled when intercepted by biophysical data collection sites (“transects”) or when randomly selected within each microwatershed (Gardner et al: 2013, data suplement). The microwatershed selection followed the principle of representativeness within classes of the forest cover gradient generated from remote sensing information.

The database that emerged from the survey is referred as RASDB and the reader is advised to consult Gardner et al (2013) and Morello (2013) for further details.

Next subsections details the procedures employed for building the variables of the econometric model.

Figure 2 Santarém, Belterra and Paragominas in the Brazilian Amazon



**4.2 Land use factor**

The land use factor was not the object of any question of the survey, but it is possible to estimate it from the formula , coming from one of the constraints of the theoretical model. There are 18 farmers in the sample that do not practice FBA, obtaining nutrients for growing annual crops solely from fertilizers. These cases are understood as the practice of a zero level of fallow, or, equivalently, with a full (100%) land utilization, i.e., 𝛾=1.

**4.3 Proxying market accessibility**

Owing to the cost of conducting data collection, the database available covers two small regions of Brazilian Amazon, both located in the same state, Pará. Within each region, the sampled farms are proximate[[14]](#footnote-14) and thus tend to differ negligibly in terms of the market prices faced. That is because, the closer two farms are, the larger the probability of exchanging inputs and outputs in common local markets[[15]](#footnote-15).

A consistent way out is to use not the market prices but the prices actually paid by farmers, wM + dM, or received, pM ‑ dM, where wM is the market price of a generic input and, pM of an generic ouput, and dM the transport cost. This way, all the variation of the explanatory variable along the cross-section of farms concentrates in the term dM.

A measure for dM, coherent with the economic theory, is the opportunity cost of the time invested in travelling to the nearest market (Duflo et al: 2008). To proxy this opportunity cost, the travel time, declared by respondents, is employed, given the unavailability of a measure for the opportunity cost per unit of time (minute, hour). The imprecision of such proxy is (partially) mitigated by focusing in a subsample of small scale farmers engaged mostly on annual cropping, what reduces the variation of the opportunity cost of time.

The nearest market for outputs and inputs, for its turn, can be proxied by the location of the nearest urban centers. The main drawback of this approximation is to make undistinguishable the individual effect of the three prices considered, namely, the price of output, p, the price of fertilizers, w and the price of labor c.

For the case of the price of labor, the proxy can be better justified with the idea that the wage farmers pay for local workers is related with the wage paid at the labor market located in the nearest urban center net of the commuting cost (see, for instance, section 10.6 of Hoover & Giarrantani: 1999 and the chapter 3 of Fujita & Thisse: 2002).

Adopting the proxy to sum up the prices that affect the optimal level of the land use factor, the model reduces to:

𝛾o = 𝛽0+ 𝛽1urb\_t + 𝛽2Ω + 𝛽3K + u

Where urb\_t is the travel time to the nearest urban center.

**4.4 Measuring fallow-yield knowledge with limited data**

The available data is limited in two crucial senses. First, it covers only one period of time, 2009, what blocks the estimation of the effects of learning dynamics. Second, it is precarious in what regards to crop, inputs and labor prices and also in respect to the amounts of inputs and factors used. Profits associated with particular fallow durations cannot be estimated.

Conclusively, to build a measure of knowledge about the fallow-yield relation in the basis of monetary pay-off, such as the one employed by Cameron (1999), is unfeasible.

The sole basis for obtaining indicators that capture observed features of past decisions regarding the land use factor lies on the recall data available. Areas allocated for specific land uses, such as annual crops and secondary vegetation was declared form 2009, 2006 and for the first year where the farmer has managed the farm. Unfortunately, recall data for fallow duration is not available and not even a physical measure of yields obtained from some relevant set of annual crops.

The following “feasible proxies” for accumulated knowledge are available in the data.

1. Binary variable indicating whether the farmer has ever being contemplated with rural extension services, “rural”;
2. Duration of time managing the farm, “exp”, a rough measure for farmer’s experience[[16]](#footnote-16);
3. Binary variable indicating whether the farmer has educational above the lower secondary level, “educ”;
4. Standard deviation of the area annually cropped, considering three years: the first year managing the farm, 2006 and 2009, “vol”.

The educational level dummy indicates with unitary value that the person that answered the questions regarding land use and production has educational level above the “lower secondary level of education”, as defined by the International Standard Classification of Education (ISCDE 1997, OECD: 2011, p.9). The goal is to control for the level of human capital hold by the agents that make land use decisions (Vosti & Witcover: 1996, Alix-Garcia et al: 2005, p.229, Parman: 2012, p.17), what is related to the ability to obtain and analyze the relevant information (Parman: 2012, p.17, Schultz: 1975).

The rationale of measure (4) comes from the assumption that farmers follow trial-and-error procedures to find the optimal land use factor, what means experimenting with the value of this variable. A change in the land use factor, in a FBA system, always come together with (i) a change in F and; (ii) a change in the ratio between cropping and fallowing, in an areal basis. Only the value of F in 2009 is observed, hence it is not possible to infer whether the land use factor has changed from (i).

The land dedicated to fallow is also not observable. The recall data available for land use does not distinguish fallow from the other purposes that secondary vegetation might be devoted to, such as ecological conservation or mere cover to residual areas with high slopes and/or degraded soil or other characteristics that make them unsuitable/unprofitable for agriculture (Perz & Walker: 2002, p.1011). As it is generally the case ‑ take, for instance, the last Brazilian Agricultural Census, IBGE (2010), p.34-36 ‑, the categories in which the survey classifies forestland refers overall to land cover and not to land use (Perz & Walker: 2002, p.1011).

The only feasible proxy for past changes in the land use factor is the variability of the area annually cropped, which is observed for the first year the farmer has managed the farm, 2006 and 2009.

Adding the four measures for K to the model, one has:

𝛾o = 𝛽0+ 𝛽1urb\_t+ 𝛽2Ω + 𝛽3rural + 𝛽4exp + 𝛽5educ + 𝛽6vol + u

**4.5 Further covariates**

The only measure available for the biophysical profile of the farms is the average slope of the terrain, a topographic feature that can be related with erodibility of farm’s soil (Blanco & Lal: 2008, table 1.3, p.9) – what makes it a relevant indicator of the effectiveness of fallow management to provide nutrients for annual crops. The average slope is calculated for buffers of 100 meters from farms headquarters – the location of headquarters is the only information available in RASDB for capturing the location of farms.

A dummy variable is included in order to capture peculiarities of the two regions not controlled by other factors.

Owing to significant correlation between the regional dummy and the measure for experience, it was necessary to add an interaction term (reg \* exp).

**4.6 Econometric model and estimation sample**

The final empirical model, adjusted to the limits of the data available, is as follows.

𝛾o = 𝛽0+ 𝛽1urb\_t+ 𝛽2slope + 𝛽3rural + 𝛽4exp + 𝛽5educ + 𝛽6vol + 𝛽7reg + 𝛽8reg\*exp + u

To estimate it, ordinary least squares with heteroskedasticity-robust residuals is employed and also fractional logit and probit models (also heteroskedasticity-robust) since they are specially designed for fractional dependent variables (Papke & Wooldridge: 1996).

Only farmers with positive areas allocated to annual crops in 2009, excluding soybean producers, are accounted for. The exclusion is justified owing to the goal of focusing only on crops traditionally grown with FBA, what is not the case of soybean, a crop recently (on the 90’s) introduced in the Brazilian Amazon, that were since form the start, cultivated with tractor-and-fertilizer-intensive methods (Garret et al: 2013, p.265).

Further exclusions were needed, owing to data availability. Farmers that have not declared whether they practiced fallow or not were excluded, as well as farmers that have not declared whether they use fertilizers (chemical or organic) or not. Farmers that declared to use neither fertilizers nor conduct fallow but had positive annual crop areas were excluded, since there are no other sources of nutrients for corps. These cases, therefore, can only be are due to survey errors or to misinterpretation of the questions.

Not all farmers have declared the size of the area allocated for annuals for the three years asked, the first year managing the farm, 2006 and 2009. Some farmers have declared a zero value for at least one of these three years. Both of the cases (at least one missing or a zero declaration) were excluded from the subsample, in order to end with the most precise numbers for the volatility of the annual area.

Farmers that are managing the farm for less than five years are also not accounted for in order to guarantee that the, for no farmer, the first year of management coincides with 2006. What ensures that all farms had the opportunity to experiment with the land use factor in all periods that comprise the observation window.

Finally, three outliers for the total farm land are not accounted for (their areas are more than 170 times larger than the 90° percentile of 100 hectares) and as well as one outlier for the volatility of the annual area (with an value more than 30 times larger than the 90° percentile of 2,3 hectares).

The variables of the model are listed on table 2 and their statistical summary can be consulted on table 3. Table 4 presents some statistics for the allocation of farmland among alternative land uses. Table 5 lists the composition of the sample in terms of fallow duration and also of the practice of FBA.

**5 Results and discussion**

It results that the variation of the land use factor, across farmers, is explained not only by variables that determine its optimal level, as attested by the statistical significance of the travel time to the nearest urban center (table 6), but also by the knowledge in basis of which farmers seek to achieve such level. The period during which the farm is managed and also the educational level are statistically significant predictors of the effective land use level (table 6).

The role of self-conducted experiments has also to be highlighted. The average volatility of the area annually cropped is a proxy for the magnitude of the changes in the land use factor conducted by farmers in the recent past. Such changes are revealing in the sense that they bring new information regarding the relation between the land use factor, at one side, and the yield and the profit, at the other side. They are crucial for building knowledge about such relation, especially for farmers whose main source of information regarding technical practices are self-experience and the experience of their relatives, as it is the case of the sampled farmers.

This is corroborated by the results (table 6), since the volatility of the area annually cropped (“vol”) explains a statistically significant part of the cross-sectional variation of the dependent variable.

**Table 2 Variables of the model**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **N** | **Variable** | **Notation** | **Measure for?** | **Unit** |
| **0** | Land use factor | 𝛾 | dependent variable | percentage (100%) |
| **1** | Travel time to the nearest urban center | urb\_t | Market access | minutes |
| **2** | Slope within 100m of farm headquarters | slope | Biophysical features of the farm | percentage (100%) |
| **3** | Dummy for rural extension ( = 1 if the farm has even being visited by an agent, 0 otherwise) | rural | Knowledge | binary |
| **4** | Duration of residence | exp | Knowledge | Years |
| **5** | Educational level dummy ( = 1 if the farmer has educational level above the lower secondary, 0 otherwise) | educ | Knowledge | binary |
| **6** | Volatility of the land area annually cropped | vol | Knowledge | hectares |
| **7** | Region dummy | region | Regions' peculiarities | binary |
| **8** | Interaction between the regional dummy and duration of residence | reg \* exp | Knowledge | years |

**Table 3 Statistical summary of variables**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Variable** | **N** | **Mean** | **Standard deviation** | **Minimun** | **Maximum** |
| 𝛾 | 125 | 0,33 | 0,29 | 0,09 | 1,00 |
| urb\_t | 125 | 111,04 | 64,31 | 5,00 | 300,00 |
| educ | 125 | 0,08 | 0,27 | - | 1,00 |
| rural | 125 | 0,33 | 0,47 | - | 1,00 |
| exp | 125 | 21,33 | 13,55 | 5,00 | 60,00 |
| vol | 125 | 0,95 | 1,61 | - | 9,53 |
| reg \*exp | 125 | 4,45 | 8,86 | - | 42,00 |
| region | 125 | 0,30 | 0,46 | - | 1,00 |
| slope | 125 | 3,76 | 2,61 | - | 14,33 |

Source: subsample of RASDB designed for the paper’s econometric analysis.

**Table 4 Land use profile of farms in the subsample**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Stats** | **Annuals** | **Vegetables** | **Perennial** | **Pasture** | **Silviculture** | **Secondary forest** | **Primary forest** | **Timber** | **Total** |
| N | 125 | 125 | 125 | 125 | 125 | 125 | 125 | 125 | 125 |
| N(a = 0)a | - | 111,00 | 93,00 | 74,00 | 115,00 | 11,00 | 64,00 | 124,00 | - |
| mean | 3,77 | 0,16 | 0,32 | 9,78 | 0,53 | 18,49 | 15,74 | 0,40 | 49,18 |
| sd | 12,22 | 0,70 | 0,89 | 28,84 | 3,43 | 23,16 | 33,03 | 4,47 | 65,37 |
| p50 b | 1,25 | - | - | - | - | 11,70 | - | - | 24,70 |
| p90 c | 5,50 | 0,25 | 1,00 | 25,00 | - | 45,40 | 60,00 | - | 99,55 |
| Min | 0,25 | - | - | - | - | - | - | - | 0,90 |
| Max | 125,00 | 5,11 | 6,37 | 254,50 | 35,00 | 135,40 | 215,00 | 50,00 | 492,00 |

a Number of observations with zero value for the area of the corresponding land use; b 50° percentile; c 90° percentile.

Source: subsample of RASDB designed for the paper’s econometric analysis.

**Table 5 Practice of FBA, fallow duration (F) and land use factor (𝛾) in the subsample**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **FBA?** | **F** | **𝛾** | **Count** | **%** |
| No | 0 | 1 | 18 | 14% |
| Yes | 1 | 0,09 | 4 | 3% |
| Yes | 2 | 0,11 | 2 | 2% |
| Yes | 3 | 0,13 | 1 | 1% |
| Yes | 4 | 0,14 | 6 | 5% |
| Yes | 5 | 0,17 | 25 | 20% |
| Yes | 6 | 0,20 | 27 | 22% |
| Yes | 7 | 0,25 | 30 | 24% |
| Yes | 8 | 0,33 | 7 | 6% |
| Yes | 10 | 0,50 | 5 | 4% |
| **Total** | | | **125** | **100%** |

Source: subsample of RASDB designed for the paper’s econometric analysis.

Even after controlling for the factors that explain the cross-sectional variation of the optimal levels of the land use factor, knowledge measures still have a role to play in explaining the remaining variation. This means that there is a significant part of the difference in the land use factor effectively practiced by farmers that is explained by the peculiar ways in which they deviate from their individual optimal levels for the land use factor. And also that knowledge proxies explain a non-negligible fraction of such peculiar deviations.

Under the light of the theoretical model, results can be interpreted as an evidence that the land use factor selected by farmers of Paragominas and of Santarém-Belterra does not coincide with the optimal. If it would, the knowledge proxies would be insignificant predictors. This means that land is being under or over utilized and it can be claimed, in the basis of the results, that one of the reasons for this is the lack of precise knowledge regarding the basic agronomics of FBA.

**Table 6 Estimation results**

|  |  |  |  |
| --- | --- | --- | --- |
| Dependent variable: 𝛾 | |  |  |
|  | **OLS** | **FLOGIT** | **FPROBIT** |
| urb\_t | -0,00118\* | -0,00628\* | -0,00339\* |
| ( 0,00053 ) | ( 0,00283 ) | ( 0,00155 ) |
| slope | -0,01036 | -0,07834 | -0,04113 |
| ( 0,00897 ) | ( 0,04565 ) | ( 0,0261 ) |
| rural | -0,04047 | -0,19234 | -0,1277 |
| ( 0,04754 ) | ( 0,22628 ) | ( 0,13757 ) |
| exp | -0,00288\* | -0,01470\* | -0,00864\* |
| ( 0,00121 ) | ( 0,00582 ) | ( 0,00351 ) |
| educ | 0,30503\*\* | 1,37960\*\* | 0,86704\*\* |
| ( 0,1084 ) | ( 0,47989 ) | ( 0,31045 ) |
| vol | 0,03881\* | 0,18238 | 0,11625\* |
| ( 0,01835 ) | ( 0,09494 ) | ( 0,05867 ) |
| region | 0,04911 | 0,29365 | 0,16316 |
| ( 0,10112 ) | ( 0,46472 ) | ( 0,28339 ) |
| reg\*exp | 0,00368 | 0,01408 | 0,0087 |
| ( 0,00535 ) | ( 0,02184 ) | ( 0,01411 ) |
| cons | 0,48328\*\*\* | 0,15215 | 0,02904 |
| ( 0,07074 ) | ( 0,34065 ) | ( 0,19966 ) |
| **N** | 125 | 125 | 125 |
| **r2\_a** | 0,30452 | DA | DA |
| **F** | 7,16471 | DA | DA |
| **chi2** | DA\* | 42,18792 | 43,2471 |

\*Does not apply; Standard errors in parentheses \* p<0,05, \*\* p<0,01, \*\*\* p<0,001

Source: subsample of RASDB designed for the paper’s econometric analysis.

**6 Conclusion**

The goal of the paper is to look for evidences that learning shapes the management of fallow and cropped area by practitioners of FBA in the Brazilian Amazon. From survey data relative to the year of 2009, the pertinence of such endeavor is corroborated: most of the proxies of knowledge are statistically significant predictors of the level of the land use factor.

A policy that aims to eradicate FBA, or to replace it for some “green-revolution” system (i.e., for a fertilizer-and-machine-intensive agricultural system), risks throwing the baby away with the bath water. The determinants for the unsustainability of FBA do not necessarily lie in the nature of the system in itself (it is not a matter of bad technology), but on the constraints that shape its management in the context faced by Amazonian farmers, which are related with capital, credit and also, as the paper evidenced, knowledge. More investment on rural extension seems a better policy recommendation, but only if such additional investment envisages building a rural extension that is not only informative but formative. I.e., farmers have to be trained to manage sustainably their land and not left on their own to freely experiment without any method.

The results are also relevant in what regards the agenda of research on the economics of FBA, since it suggests that knowledge cannot be ignored as part of the factors driving farmers’ behavior.

Understanding how farmers learn about the management of FBA systems is perhaps fruitful way to understand how they can learn about agroforestry systems whose foundation also lays on synergically combining agriculture and forest management. Agroforestry systems are recommended by multilateral organizations and research institutes, such as the World Agroforestry Centre (ICRAF; see Tomich: 2009) and EMBRAPA (Brienza Jr et al: 2009), as a superior alternative, in terms of welfare and environmental conservation, for smallholders still locked in on fire-based fallow agriculture.

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1. The term fallow-based agriculture is adopted in the text, instead of the most common denomination “slash-and-burn agriculture”, as a more general definition that can comprises agricultural systems that depend on secondary vegetation but not necessarily on fire, such as it is the case of the slash-and-mulch system – this system is object of research by the Brazilian Agricultural Research Corporation (EMBRAPA) since the end of the 1980’s and has being adopted by smallholders (Denich et al: 2005, Comte et al: 2012). The terminology is intended to emphasize the focus of the paper which does not lay on fire use but on fallow management. [↑](#footnote-ref-1)
2. “Our interviews indicate that the farmers first burn and clear a plot of mature forest ("mata") or mature secondary forest ("capoeirao") after they have removed valuable wood products that can be sold or used for domestic purposes. This land is then planted in rice and various crops for a period of 1 or 2 years (Fig. 3). The plot is then fallowed for 1 or 2 years, given a light burn to remove the weedy "juquira" vegetation, and re-planted with a short fallow cropping sequence (Fig. 4). Following this cropping, the fields are fallowed for 3 to 6 years, cleared of their "capoeirinha" vegetation and re-planted with amid-length cropping sequence (Fig. 5). If the productivity of the site is considered high, this mid-length fallow is repeated and followed by a short fallow cropping sequence. If site produtivity is considered low, the field is fallowed for 8 to 12 years before its "capoeira" vegetation is cleared and the plot is returned to cultivation (Fig. 6). Depending on the decisions made by the farmer, it can take between 12 to 22 years to complete this entire cultivation cycle on any individual field (Scatena et al: 1996, p.35).” [↑](#footnote-ref-2)
3. What, according to the author “capture[s] the time a household has had to learn locally appropriate agricultural practices (Perz: 2003, p.145).” [↑](#footnote-ref-3)
4. Or Rutheberg’s R (Kato et al: 1999 and Angelsen: 1994). [↑](#footnote-ref-4)
5. A problem equivalent to the one seminally solved by Faustmann that involved the determination of the optimal rotation of an espontaneous growth forest (Conrad: 2010, section 4.3). [↑](#footnote-ref-5)
6. This convention is a way to deal with the fact that, on the data available, fallow duration is observed for only one point in time, what prevents the construction of a measure of knowledge based on past experiments with possibly distinct fallow durations. But recall data on cropped area is available, what allows for building a measure based on past experiments with possibly distincts ratios of fallowing and cropping, i.e., 𝛾. [↑](#footnote-ref-6)
7. Optimal rotation models are apprehended in the timely dimension as dynamic processes governed by intertemporal decisions (see chapter 4 of Conrad: 2010). [↑](#footnote-ref-7)
8. The assumption of C =1 is justified in basis of estimations for C from the ratio of the area cropped by the area treated with fire in the same year, as table below shows. The rationale comes from the fact that, under perfect rotation, the agent cultivates, in a given year, an extension of land that is equal to the area slashed and burned in the same year (or on the subsequent year, depending on the production schedule) plus the area slashed and burned on the last C ‑ 1 years (or C – 2 if the slashing occurred on the last year), when each piece of land is cropped during C years. A tolerance of 0.05 years (0.6 months) was used to round the ratios, thus obtaining integer values for C. For the two years for which the estimation was possible, almost 75% of the farmers registered an estimated land use factor equal to the unity.

   |  |  |  |  |  |  |  |  |  |  |  |
   | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
   | **Year** | **count** | **min** | **Max** | **Mean** | **sd** | **p10** | **p25** | **p50** | **p75** | **p90** |
   | 2006 | 157 | 0,02 | 3,08 | 1,10 | 0,43 | 1,00 | 1,00 | 1,00 | 1,00 | 2,00 |
   | 2009 | 157 | 0,06 | 8,00 | 1,11 | 0,70 | 0,84 | 1,00 | 1,00 | 1,00 | 1,50 |

   Source: RASDB (see section 4.1 below). [↑](#footnote-ref-8)
9. Even referring to another context, the results obtained by Duflo et al (2011) are enlightening: they show that agricultural techniques (the use of chemical fertilizers, particularly) may be employed in a non-optimal way, from the economic point of view, due to small fixed costs, including the cost of learning how to manage them. [↑](#footnote-ref-9)
10. As Arrow classically stated: “Learning is the product of experience. Learning can only take place through the attempt to solve a problem and therefore only takes place during activity (Arrow : 1968, p.155).” [↑](#footnote-ref-10)
11. The similarity with hill-climbing and other iterative optimization algorithms is clear (Russel & Norvig: 1995, section 4.4). [↑](#footnote-ref-11)
12. In the sense of Simon (1956). [↑](#footnote-ref-12)
13. A type of correlation that is common among learning by doing models, where present decisions, regarding, for instance, the output level depend on results from past decisions, such as the accumulated investment or output (Arrow: 1968, p.157-160, Arifovic & Karaivanov: 2010, section 3.1). [↑](#footnote-ref-13)
14. The largest distance between farms in the Paragominas region is of 185 km and, for Santarém-Belterra, of 118 km (Morello: 2013, section 4.2.1). [↑](#footnote-ref-14)
15. This statement finds support on the “hotellian” localized competition models (Firgo: 2012, p.5), traditionally employed on the study of agriculture markets (Faminow & Benson: 1990, p.50), which assumes that “farmers differentiate between buyers [of outputs] on the basis of location” (Faminow & Benson: 1990, p. 50). [↑](#footnote-ref-15)
16. “Duration of residence indicates the degree of a household’s experience at farming in the Amazon (Perz & Walker: 2002, p. 1014).” [↑](#footnote-ref-16)