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Testing a poverty trap mechanism
with Tsimane' panel data

Emilie Perge[1], University of Sussex
e.perge@sussex.ac.uk

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Abstract:

Even if people have asserted the existence of poverty trap within forest, it has never been empirically tested that forest and poverty interactions lead to a poverty trap from which poor forest people could not escape (Angelsen and Wunder, 2003). This article tests if such a mechanism arises within forest communities and analyzes the different livelihoods forest people could implement. Data used are from the Tsimane' Amazonian Panel Study (TAPS 2002-2006) have been complemented by qualitative data collected in June-July 2008. The poverty trap mechanism studied is inspired by Carter and Barrett's model defined for their studies of agrarian communities (Carter and Barrett, 2006). They intend to show that an S-shape exists in the asset accumulation process of households due to the presence of increasing returns to assets at an unstable equilibrium. An asset index is computed through factor analysis to estimate the asset accumulation process. To test the S-shape, different regression techniques are used: parametric, nonparametric and semiparametric. The parametric regression uses a fourth-degree polynomial regression to estimate the relationship between the change in asset index and its lagged value. For both nonparametric and semiparametric regressions, penalized splines and LOWESS estimators are used. All three regressions show that a poverty trap mechanism does not occur for the Tsimane', there is no S-shape in the asset accumulation and it seems concave. These results contradict Carter's and Barrett's results because here Tsimane' households have a wide range of activities and assets. Households rely on diverse assets to achieve their livelihood. They use forest resources in addition to agriculture, so they are not pushed further into poverty if forest resources are depleted, they would rely more on agriculture as also land constraints are weak.

1. Introduction

The situation of people living within forests has been characterised as precarious in terms of wealth, health, education and environmental conditions, and researchers have often concluded that downward spirals are arising leading to a poverty trap from which forest people could hardly escape (Angelsen and Wunder, 2003). This conclusion has been drawn from a focus on linkages between forest resources, as a main component of forest people livelihoods and their well-being.

Forest people are closely dependent upon forest resources and have a great impact on their evolution (CIFOR, 2003). They use forest resources to meet their basic needs, e.g. food, shelter, furniture, raw materials (Arnold and Townson, 1998; Coomes and Takasaki, 2004; Wunder, 2001), or to develop different types of activities including hunting, gathering non-timber forest products (NTFPs), farming, logging, trading handicrafts products (Byron and Arnold, 1999; Sunderlin et al., 2005). Forests have a great impact in modelling social relationships, as they are differently used at individual, family or community levels and they participate widely into the spiritual life of the people as they are often considered as burial, sacred sites, spirit home (Ritchie et al., 2000).

Even if they are still highly dependent upon forest resources, it seems that more frequently forest people develop livelihood strategies relying on more diversified activities and assets. What I would like to test in the following analysis is whether this type of livelihood strategies would lead households living within forests to a poverty trap situation explaining why forest households cannot reach higher levels of development or whether their low levels of development are due to slow growth rates in their consumption, earnings or asset holdings but whose improvement would arrive through time.

This would be an application of a poverty trap mechanism developed by Carter and Barrett and that relies on assets as a way to escape poverty trap through asset accumulation (Carter and Barrett, 2006; Carter and Barrett, 2007; Barrett, 2007). To proceed to the application of their mechanism and to the test of a poverty trap with forest households, the remainder of the paper is organised as follows. In a second section, forest communities and households on which the test would be drawn are presented in order to justify the interest in such a test for these households. A third section would describe the poverty trap mechanism as defined by Carter and Barrett, and woul show its early applications to different types of communities. A fourth section would be dedicated to construct the different elements required to proceed to the test, such as an asset index and the identification of different livelihood strategies. Afterwards, in a fifth section I would test the poverty trap mechanism using different estimation techniques: parametric, nonparametric and semiparametric. The final section would conclude and give further implications towards which future analyses could focus.

2. Research area and data

The test of a poverty trap mechanism requires panel data in order to analyse the evolution of the economic situation of the agents. Since 1999, an international research centre composed by different Bolivian, US and European researchers have compiled data on an indigenous forest population, the Tsimane' and created a rich panel data set well designed to test a poverty trap.

2.1. Presentation of the Tsimane' population

The Tsimane' are a native Amazonian population living in the plains and rainforests of Béni in Bolivia. The Tsimane' territory represents 1.2 million of hectares. In the last census from the Vice-Ministry of Indigenous Affairs, the Tsimane' population exceeds 8,000 inhabitants while they were only 5,000 inhabitants in 1995. Traditionally a semi-nomadic population, they have settled in 100 communities mainly situated along the Maniqui and the Apere rivers even if they still move from one community to another (Godoy and Jacobson, 1999; Reyes-García, 2001; Apaza et al., 2002). The main town in the area is San Borja where the Tsimane' can go to sell their products and buy the different goods they need. San Borja has different health amenities, such as a public hospital, doctors and an evangelist dispensary. Here they can also find schools up to the highest grade before university and different transport services to the capital-city La Paz, to Santa Cruz and other towns (Godoy et al., 1998; Reyes-García, 2001).

The Tsimane' practice traditional slash-and-burn agriculture and cultivate rice, maize, manioc and plantains. This type of agriculture consists in clearing forest with machete and other small tools from May to August, then they set fire in September-October and finally they plant once the plot is totally cleared starting by sowing rice. After the rice harvest, they plant maize, manioc and plantains. The cultivation cycle of these staples lasts only one or two years after which the plot is left in transition for forest regeneration and they clear another plot. After a normal period of five years a former plot will be cleared again (Godoy et al., 1998; Vadez et al., 2003; Reyes-García, 2001). Agriculture is their predominant activity as both a source of consumption products and source of earnings. They fulfil their protein needs through hunting of small animals and big games, and through fishing which justifies their localization along the rivers. But the extinction of game has led them to raise chicken and pigs in order to fulfil their protein needs (Vadez et al., 2003; Reyes-García, 2001).

Historically, the Tsimane' were living in autarky, without contacts with outside agents. But the extraction of natural resource, such as gold, quinine, rubber, in the late 19th century and the beginning of the 20th century, led them to multiply contacts with the outside economy. In the 1920s, while the extraction of these different resources declined, cattle ranching and logging activities have become more important and the Tsimane' have started working as unskilled labourers either clearing forests for cattle ranchers or finding valuable trees for loggers (Apaza et al., 2002; Reyes-García, 2001). Next to these wage activities, they have increased their contacts with outside agents through the expansion of commercial activities. Traders have come frequently to the communities in order to buy/barter agricultural products (rice, maize, manioc and plantains), forest products and hunting game, and to sell durable goods, e.g. clothes, radios, batteries, tools, alcohol and sugar (Apaza et al., 2002; Reyes-García, 2001; Godoy et al., 2008).

Catholic and protestant missionaries have started coming to the indigenous territories during the colonial period with the goal to evangelize them. But the Tsimane' have remained mainly animist and the main contribution of these religious organizations has been the development of monolingual and bilingual schools in Tsimane' and Spanish, the implementation of dispensaries and the creation of a radio emission that allows the Tsimane' to communicate from one community to another (Reyes-García, 2001).

To these external influences, the Tsimane' have adapted certain aspects of their way of life but none more so than their community organization. They became more and more sedentary and have changed the composition of their communities which are now larger with three to eight related families, and whose authority has been transferred from a shaman to an elected corregidor more integrated into the market economy (Reyes-García, 2001).

2.2. Data: quantitative TAPS data and qualitative data

a) Quantitative data: TAPS

Since 1995, the TAPS (Tsimane' Amazonian Panel Study) has been collecting data on the Tsimane' to analyse the evolution of different welfare indicators. The final panel data available encompasses five years (2002 to 2006) as the first seven years of the surveys have been dedicated to "identify communities, win the trust of the villagers, train local researchers, build logistical infrastructure,

and refine methods of data collection" (Leonard and Godoy, 2008). The data available through the panel covers around 332 households, comprising nearly 1,985 individuals who have been interviewed every year since 2002 . Out of the 100 Tsimane' communities in Béni, the panel data survey relies on 13 villages located at different distances from the main town of San Borja, and while some of these are connected to San Borja by roads, other villages are located along the Maniqui river and only accessible by canoe.

The goal of this data collection has been to analyse the effect of the market economy on the well-being of the Tsimane' through data on demography, agriculture, income, consumption and expenditures, the shocks they faced as well as their psychological status (Leonard and Godoy, 2008). The economic data that the research team have gathered are interesting and well developed. They encompass measures of the Tsimane' income according to different sources like wage, sales, barter and remittances. They look at their agricultural activities as well as their forest-product extractions through for instance hunting and use of medicinal plants. They have collected data on their food consumption, their different expenditures and their assets (Leonard and Godoy, 2008). While generally well developed, the data are quite limited when looking at the size of fields and land holdings, as well as the different wage activities the households could undertake. Some data on gifts, education were reported only from 2004 and not over the five waves.

b)Qualitative data

When first analysing the data, some questions concerning wage activities, their living conditions and organisation have arisen. Therefore, I have collected qualitative data through observations as well as individual and collective interviews in different Tsimane' communities. Goals that encouraged my fieldwork were: to obtain a better understanding of the relations between the Tsimane' and the forest resources, to learn how dependent upon their resources they are, to understand what motivates them to participate or not in wage activities, to appreciate what their rationality is considering the future and finally to apprehend how organized they are both within the community and in their interactions with non-indigenous communities.

My fieldwork took place during five weeks in June-July 2008. I went to nineteen villages, most of them were accessible by motorbike, but some were only accessible by canoe. In average, the time needed to reach most of them varied from half an hour up to an hour or so. I was accompanied by

a translator who has often been working with the TAPS researchers and was known by all the Tsimane' we interviewed. The interviews lasted up to half-an-hour and were either run individually or with different members of the household, or more collectively with members of different households. Generally I interviewed the male head of the household in their houses as men participate more in wage activities than women. When male heads were away, I tried to ask the questions to their wives but most of these interviews were unsuccessful as they were not willing to answer my questions, or busy taking care of their children. As often as I could, I tried to interview both the corregidor who is the official representative of the community and the teacher who is also an important leader within the community. I attended different community meetings where I gained an insight into both the strength of community among the Tsimane' and also how democracy works in these communities.

Considering the findings and observations I can start by inferring that all the villages visited were either small or widely geographically spread, with the school in the centre of the village. There was no market place in the villages, nor were there official buildings representing either the Tsimane' governing body or the Bolivian government. Sense of community was lacking with the regard to certain villages as they consisted merely in two or three families living one next to the other. Other descriptive findings from the qualitative and quantitative data are drawn below.

2.3. Descriptive analysis and findings from quantitative and qualitative data

a) Demographic features and living conditions

In the communities I observed that households were large and mainly composed of young members. The TAPS data shows that most of the households are headed by men aged between 26 and 45 years old. Between 2002 and 2006, as reported in Table 1, the average age of a Tsimane' household was 21 years old, the average educational attainment was a first grade in primary school while the Bolivian system counts thirteen grades.

Table 1: Description of an average Tsimane' households

	Average age	Average education	Size of household	Number of children (<15 years old)
2002	21.6	1	6.6	3.0
2003	22.0	1	6.6	3.0
2004	21.0	1	6.2	2.7
2005	30.5	1	6.5	2.7
2006	21.1	1	6.5	2.8

A Tsimane' household is composed of six members and three of them are under fifteen years old. Educational attainments of household head remain low over the period and the younger the household head, the higher educational attainment is for the household head. Young household heads have reached up to a fourth grade, while older household heads present lower levels of education. It seems that male education is improving in these communities and that households are still really young. The small number of old household members reflect that life expectancy for the Tsimane' is low.

This low life expectancy can result from their physical living conditions. I observed that Tsimane' dwellings are ground-floor houses with or without walls and with thatch-palm roof and earth floor. Most of them have everything in a single room while some have a shelter for the kitchen separate from the main room where they sleep. A few villages have access to a well but most villages did not have drinkable water, and none has a sanitation system.

b) Agricultural activities

Considering their agricultural activities, all the households I interviewed were cultivating rice, maize, manioc and plantains mainly for their home-consumption but also they allocated a part of their harvest, often half of it, to sell or barter to obtain durable goods. Each household was doing its own cultivation in nearly the same quantity and no organization or cooperative system was implemented.

The TAPS data showed that for the last three waves, from 2004 to 2006, rice production seems more important than maize production for the Tsimane'. Rice production has increased along the period from 62.4 arrobas (around 717.8kg) in 2004 up to 187.9 arrobas (2160.6kg) in 2006 (Table 2). At the

same time, their rice sales have increased between 2004 and 2006 but in a smaller quantity compared to the rice production, which has resulted in a reduction of the ratio sales on production. When looking at the rice prices in each village, it has increased in 9 villages out of 13, increasing in average by 2 to 8 bolivianos. This increase in rice prices have not been accompanied by such a large increase in sales as half of the households in each village have either increased or decreased their rice sales. The households do not seem to be really responsive to rice price variations. During the same period, the corn production and sales have decreased and the sales have decreased in a larger measure leading to a decrease in the ratio sales on production.

Table 2: Household agricultural production and sales 2004 to 2006

Products	2004	2005	2006
RICE (arrobas)[2]			
Production	62.4	85.3	187.9
Sales	35.0	46.9	35.1
Ratio sales/production	0.5	0.4	0.4
CORN (mancornas)			
Production	70.6	73.2	47.9
Sales	46.3	38.5	18.5
Ratio sales/production	0.5	0.4	0.2

Next to these main crops, the Tsimane' report doing other different crops. Most of the Tsimane' households report cultivating plantains. Other important crops are manioc, sugar cane and sweet potatoes. Only few households report having onions and peanuts.

To realise their agricultural production, the Tsimane' households have to clear a plot, and over the period, they cleared around 5.7 tareas, so half-an-hectare, of fallow forest and 3.1 tareas of old-growth forest, one third of hectare. The data in table 3 show that the areas cleared are increasing along the period. I wanted to understand what the size of the field sown with rice and corn is, but the limited availability of the data impedes to conclude on the area sown with rice. Considering the corn production, the area sown with corn has remained quite the same along the period (Table 3).

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2   1 arroba=6 mancornas =11.5kg

Table 3: Size cleared forest and cultivated areas with rice and corn (2004-2006)

Size (tareas[3]	2004	2005	2006
Cleared fallow forest	5.5	5.6	6.5
Cleared old-growth forest	3.3	4.6	4.4
Rice cultivated area	n/a	n/a	0.9
Corn cultivated area	1.3	1.3	1.3

During my interviews, the Tsimane' reported neglecting to sell the trees that were on it, in preference for drying and collecting for firewood used for cooking. Very few of them had ever sold some firewood as a way of increasing their earnings. Few households were into a 'rice strategy', which consists in increasing the cultivation of rice as its price increased and getting specialized in the production of one variety of rice instead of another as this variety could bring higher earnings.

c)Earnings and wage activities

This paragraph summarizes the different sources of earnings the Tsimane' rely on. Four broad sources of earnings have been defined by the TAPS researchers: sales, wage, barter and remittances. In the five waves, the earnings generated through wage seem to be the most important, except in 2005 when the Tsimane' households did receive more earnings from sales (Table 4). But what is interesting is that even if the earnings from wage are the most important they are not the most important in terms of participation as more households report earnings from sales and even in some years from barter. The values of remittances received during the period are really high, but less than ten households report them.

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3   10 tareas = 1 hectare

Table 4: Nominal earnings in bolivianos (US$1=6.970Bol.) during the last two weeks

Years	Sale		Wage		Barter		Remittances		Total earnings	
	N	Bol.	N	Bol	N	Bol	N	Bol.	N	Bol.
2002	116	144.5	99	169.6	101	31.6	9	253.3	173	225.6
2003	109	159.1	88	194.8	106	34.5	8	307.8	163	249.1
2004	128	134.7	117	244.8	113	35.2	9	131.3	196	260.5
2005	145	267.9	119	253.4	115	51.9	8	121.3	196	387.5
2006	128	215.7	116	293.8	124	46.3	4	543.8	189	368.3

What the qualitative survey reveals is that for households taking part to a wage activity such as working with a cattle rancher or working for a logger, for the ones I could talk to, their main motivation for participating in such an activity was to cope with an unexpected expenditure such as buying medicines or tools. They were working with these persons on a daily or contract basis, from times to times. The ones who worked more regularly in a wage activity were not present in the household while I was there, as a more permanent tenure of labour required their relocating to live on ranch or logging company property. Temporary work with a cattle rancher consists generally in clearing forest areas and building fences, while a more permanent employment means that they can take care of the cattle and have more responsibilities. The individuals working more permanently were young men of the household, not married, and their wage was used to help their family to face with events and to buy clothes. In the case of important emergency, they said that they can ask the cattle rancher they usually work with for loans and would repay them by working for them. Their main argument not to work every day was that it is tiring and they are not willing to follow someone else rules and orders. They rather prefer working on their own than working with and for someone.

d)Consumption and assets

Looking at the consumption values, I decided to consider the deflated values of consumption aggregates and I calculated a consumer price index using price data. The average consumption of the Tsimane' households has increased between 2002 and 2003, then decreased in 2004, increased between 2004 and 2005, and finally decreased between 2005 and 2006 but the 2006 average value

remains higher than in 2004 (Table 5).

Table 5: Household consumption aggregates between 2002 and 2006 (deflated values to 2004 prices)

Years	Farm products	Oil products	Market meat	Starch products	Domestic meat	Wildlife products	Total consumption
2002	37.3	7.6	25.1	21.7	9.9	147.3	248.4
2003	38.7	6.0	24.4	18.0	11.4	130.4	229.2
2004	21.9	5.8	20.5	17.2	8.5	161.6	235.6
2005	39.3	8.6	26.7	46.8	9.3	167.3	298.1
2006	53.3	14.5	39.2	46.5	15.5	123.0	292.0

The largest part of their consumption was composed of wildlife products (birds, fish and game), then of staple products that are assumed to be home-produced. The latter one has increased since 2004 and main products consumed were plantains and rice. The total consumption aggregate has decreased between 2005 and 2006 it is explained by the decrease in wildlife consumption. What is interesting to highlight is that most of their consumption was generated by home-production either agricultural activities or hunting and fishing.

Looking at their asset holdings, in average, their total wealth has increased since 2002, from 3896.4 bolivianos in 2002 up to 4966.6 bolivianos in 2006, but with a small decrease in 2003 and 2004 (Table 6). The main asset holdings of the Tsimane' is their holdings in modern assets which include the assets the Tsimane' purchased in San Borja or from traders, such as radios, big pots, rifles, knives... Between 2002 and 2006, their modern asset holdings have increased from 2225.0 bolivianos up to 3096.0 bolivianos.

Table 6: Household asset holdings between 2002 and 2006 (deflated values to 2004 prices)

Years	Animal wealth	Modern wealth	Traditional wealth	Total wealth
2002	734.8	2225.0	936.6	3896.4
2003	555.0	2313.7	858.7	3727.4
2004	635.0	1895.1	648.1	3178.2
2005	806.4	2708.2	981.2	4495.8
2006	771.5	3096.0	1099.1	4966.6

They also have high values of traditional asset holdings that are hand-made but their values have

increased from 936.6 bolivianos in 2002 up to 1099.1 bolivianos in 2006. These assets encompass different objects from bags and bows to canoes and grinder stones. The last category of assets they can hold, is their animal assets composed of cows, ducks, chickens and pigs. It seems that over the period the holdings in animal assets have slightly increased.

Having in mind the different characteristics of the Tsimane' households and communities, and an appreciation of their well-being, a poverty trap test seems accurate. In order to proceed with the test, a typical model of poverty trap, here referred as Carter and Barrett's poverty trap mechanism has been selected and the following section will present it.

3.   Poverty trap mechanism: Carter and Barrett's model of poverty trap

Many different models have been designed to understand and explain why some individuals are ensnared in low level of economic development while others seem to enjoy greater levels of welfare. Some underline the importance of institutions, kin systems and history in the development of multiple equilibria, while others focus on the lack of insurance and the nature of risks the individuals face. Bowles et al. (2006) provide a good review of the different aspects of this mechanism and related models.

### 3.1. Carter and Barrett's poverty trap mechanism: presentation and previous applications

a) Presentation of the model

The following analysis of the poverty trap mechanism bases itself on the literature by Carter and Barrett who test such a mechanism in agrarian societies. A poverty trap could be defined as *"self-reinforcing mechanisms that act as barriers to the adoption of more productive techniques and so cause poverty to persist"* (Azariadis and Stachurski, 2004; Barrett, 2007). In their model as presented in the figure below, a household chooses to allocate its productive wealth to one of two distinct strategies. A household with a low level of assets A_L would choose to use its assets within a strategy L_1 yielding to a low level of well-being U_L while a wealthier household would choose to use its assets A_H in a higher-earning strategy L_2 leading to a higher level of welfare U_H . Both asset allocations lead to locally stable equilibria with non-increasing marginal returns. A high-return strategy has

higher returns while a low-return strategy has lower ones which creates non-convexities in the asset accumulation. Setting a static poverty line at $\underline{A}$ emphasizes the point that a household choosing to allocate its assets to a strategy L_1 is caught into poverty. Nevertheless a level of assets A_S exists from which a household rationally switches from one strategy to the other. However to reach this level of assets a poor household must have asset holdings above the dynamic asset poverty line A*, here called Micawber threshold. Below the Micawber threshold, a household has less investible surplus and depressed marginal incentives to save; above this threshold, a household rationally starts accumulating assets through an autarkic accumulation strategy (Carter and Barrett, 2006). Through asset accumulation, a household would reach a level of asset from which it switches to a low return strategy to a high return one. Finding out this threshold requires an assessment of the asset accumulation process which links the current level of assets to the future level. Plotting future asset holdings against current ones is expected to give a S-shape curve where the Micawber threshold would simply be the unstable equilibrium where the asset accumulation bifurcates (Carter and Barrett, 2006).

Therefore an asset accumulation process is what allows the convergence to the high stable equilibrium and the improvement in their welfare (Barrett, 2007). But the poorer households cannot accumulate assets, and Barrett and his co-writers point out different reasons explaining why (Barrett et al., 2006). They explain that poorer households cannot accumulate assets due to their portfolio choices. They would adopt a defensive portfolio strategy, preferring low-yield low-risk activities rather than higher-yield higher-risk activities. As returns on assets are positively correlated to their initial wealth, the rate of returns with this portfolio strategy is even less than the one the richer agents have with higher-yield higher-risk strategy (Zimmerman and Carter, 2003; Carter and Barrett, 2006). Another point they use in accounting for non-asset accumulation by the poor is the subsistence constraints they have to face. Poorer households have such low levels of consumption that they cannot reduce it more in order to increase their savings and start an asset accumulation process. A third justification deals with the lack of liquid savings and credit that does not allow them to buy more assets and start an asset accumulation (Barrett et al., 2006). Both weak development of banking system for the poor and their lack of counterpart impede them to obtain credit; this lack of credit makes them reliant on what they actually earn and have to accumulate assets which impedes their asset accumulation if their earnings are not high enough to increase their asset holdings.

Figure 1 Poverty trap from Carter and Barrett (2006)
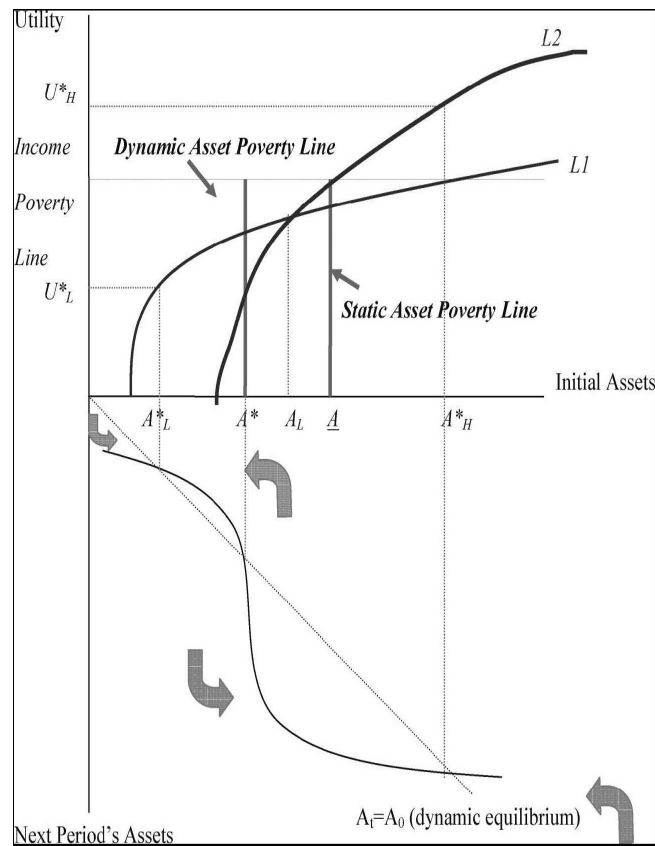
Here the analysis is centred on strategies and assets instead of on activities and income or consumption expenditures because assets are expected to better reflect the heterogeneity of the livelihoods of the poor. Further, assets are the source of future earnings, so their accumulation is what allows the individuals to reach higher levels of well-being (Coomes and Takasaki, 2004; Naschold, 2005).

b)Findings of some previous applications of the model

Lybbert et al. (2004) have studied the herd size held by Ethiopian pastoralists. They have found some non-convexities in the accumulation of their cattle leading to a S-shape asset accumulation curve with two stable equilibria: a low one corresponding to a size herd of one head range, and a higher one at herd size of 40-75 head range. They have identified a threshold level of 15 animals from which the households could rationally change their way of raising cattle and adopt a more productive one. Barrett et al. (2006) show that among Kenyan pastoralists, an S-shape characterises

their accumulation of livestock with two different stable equilibria as well as the unstable equilibria. But while studying the asset accumulation in Madagascar they have not found such a

pattern among households.

Naschold (2005) has not found a multiple equilibria pattern for the rural households in Ethiopia and Pakistan asset accumulation. The estimations he has run have presented a unique and low equilibrium.

In their estimation of a poverty trap mechanism in South Africa, Adato et al. (2006) explain why some post-Apartheid households have succeeded in escaping poverty while others are still ensnared in low levels of economic development. They use four different key assets integrated into a weighted asset index in order to estimate the asset accumulation path and the poverty dynamics among these households, so as to identify any possible S-shape in the asset accumulation. They find a Micawber threshold equal to twice the poverty line, and the households below this threshold would be captured in a poverty trap at a low equilibrium with a level of well-being about 90 percent of the poverty line (Adato et al., 2006).

Even if closer to reality than neoclassical growth models, some limits could be highlighted in poverty trap model specifications. In most of the studies, beside Adato et al. (2006), researchers have focused on populations whose livelihoods and strategies depend only upon one type of activity. Lybbert et al. (2004) as well as Barrett et al. (2006) have tested it on herders and agro-pastoralists in both Kenya and Ethiopia. These two articles refer to populations whose strategies, both low-return and high-return, are related to cattle and are highly diversified. Therefore, these studied populations rely only on one type of asset to generate their strategies, here cattle, from which it is easier to identify the presence of the different exclusionary mechanisms, like the lack of insurance when loss of animals due to disease or the lack of liquidity to buy medicines to take care of the cattle... Identifying increasing and non-increasing returns to scale linked to the different levels of cattle holdings is also a more straightforward process.

My contribution to the test of a poverty trap mechanism would be to study households whose strategies rely on more diversified activities when compared to the agro-pastoralists studied by Lybbert et al. (2004) or by Barrett et al. (2006), even if their strategies are not too diversified when compared to other groups. Another important contribution depends on the fact that I am analysing population whose strategies require different assets to generate their livelihood and not a single asset whose variation in the asset holdings influence directly their livelihood and welfare. This would allow me to demonstrate how to capture a poverty trap mechanism with more diverse asset

holdings.

3.2. Exclusionary mechanisms leading to multiple equilibria in the asset accumulation process

Market imperfections, imperfect information and coordination failures are the three main exclusionary mechanisms retained to explain why increasing returns to scale and non-convexities in the asset accumulation process arise and all three are identifiable within Tsimane' communities.

a) Market imperfections

Markets in developing countries are characterized by imperfections that would in fact impede the convergence of the growth rates in the long run. Such market imperfections could involve the existence of negative transaction costs that make the marginal returns from a higher-welfare strategy insufficient to overcome the costs of implementing such a strategy for poor households (Azariadis and Stachurski, 2004; Barrett, 2007). To implement higher-return strategies, the agents need to adopt more expensive tools or production process, therefore wealthier households are more able to adopt such tools while poorer households are unable as the costs to adopt these tools are higher than the returns. In the case of the Tsimane', they have a weak access to markets resulting from the remoteness of their communities to the main market in San Borja or Yucumo, and the lack of infrastructure impeding the furthest communities to sell their agricultural products on these markets. Also, selling products on markets requires additive costs that only few households can afford. Poorer Tsimane' households are more dependent upon traders that travel from one community to another, which leads to multiple prices of the products and lack of transparency about a fair price of the products.

The inefficiency of financial markets in developing countries leads to increase financial constraints, credit constraints and uninsured risks which restrict the poorer households from switching their actual subsistence strategy to a higher welfare strategy. The lack of legal frameworks effective in enforcing insurance contracts in developing countries has been underlined as an important source of failures in the insurance market (Carter and Barrett, 2006; Barrett, 2007). The Tsimane' do not have access to credit and insurance markets. All the credits they report have been obtained on an informal credit system as both the cattle ranchers and the loggers working with the Tsimane' agree

to lend money to the ones they work with. In 2006, 65% of the households received credits from these informal lenders. Such loans require great trust, two stakeholders know each other and repayment is done through extra-labour.

Furthermore it appears that among poorer agents risks are often covariant and not idiosyncratic which make their repayment more expensive and burdensome in poorer communities. The covariance in the risk these agents face makes informal insurance mechanisms, i.e. self-insurance, risk mitigation and risk transfer, often inapplicable among them (Carter and Barrett, 2006, 2007). Yet, even when risks are idiosyncratic their neighbours are just as poor as they are and cannot really help them (Azariadis and Stachurski, 2004; Barrett, 2007; Barnet et al., 2008). Their main insurance mechanism consists in selling more products when they need extra-liquidity to cope with an unexpected event. When they face covariant risks, such as flooding, the only way the Tsimane' can cope with such risks resides in external aid from national or international non-governmental organizations.

b)Incomplete information

The second exclusionary mechanism Barrett and Carter use to explain the existence of multiple equilibria in the asset accumulation process emphasizes the importance of imperfect information available to poor households. While explaining the limits of neoclassical growth model, creation of knowledge has been advanced as an important feature in the explanation of the divergence in growth rates in the long run (Azariadis and Stachurski, 2004). Low access to information, due to low levels of education and training as well as less diversified social networks, increases the cost of adopting a livelihood strategy relying on more complicated techniques. Also poorer individuals are unable to perfectly observe the consequences of their actions and even less the consequences of the actions of other agents, making the impacts of such actions observable only in the future. They cannot observe that the techniques used are not as productive as they expect and create more social costs than private benefits (Carter and Barrett, 2006; Barrett, 2007). The path-dependence nature of information driving the poor to create norms and institutions reflecting their available information is a crucial element in explaining why poorer individuals cannot implement higher strategy. Path dependence of the institutions impedes these ones to evolve according to emerging information even if they may be a rational response to the situation the individuals are in (Azariadis and Stachurski, 2004; Barrett, 2007). The Tsimane' endure situation in which they do not

have access to perfect and complete information. They implement techniques without knowing that better techniques or higher-yielding seeds are available how it transpires through the qualitative survey. Their low levels of education restrain them to access to better technologies and to understand how these technologies work. Limited communication due to a lack of infrastructure among the Tsimane' communities impede them to know that these technologies exist. Tight networks seem also to characterize the Tsimane' communities as the majority of them are composed with a small number of households, often blood-related households. The fact that most of the Tsimane' only speak Tsimane' and not Spanish reduces their opportunities in widening their networks with the rest of the population and then their opportunities to accede to richer information.

c)Coordination failures

The third exclusionary mechanism highlighted deals with coordination failures. The weakness of the institutions and their incapacity to control, monitor, enforce law, and provide public goods, as well as actual corruption of these institutions are reasons preventing the poorer individuals from implementing higher-earnings strategy (Barrett, 2007; Carter and Barrett, 2006). The poor definition of property rights and the prominence of common property regimes wherein agents fail both to communicate on the state of resources and the techniques they use, and to implement sustainable techniques are also barriers to the adoption of higher-earnings strategy by poorer agents (Baland and Platteau, 1996; Barrett, 2007). The Tsimane' territory is ruled by a common property system in the sense that any Tsimane' households can clear a part of it to cultivate without asking permission to anyone. This lack of property rights discourage the households in adopting more productive technologies and keep the poorest households in low-yielding activities. At the same time, investing in land does not seem to be a main issue because soil is highly fertile and agricultural process leads to clear a new land every year and to go back to a previous plot every five years. Another coordination failure proceeds from the multiplication of legal bodies to refer to when productive activities are intended. Considering forestry sector, the Gran Consejo Tsimane' gives the concession rights to the logging companies but coexisting to this institution, the Superintendance of Béni which is not a Tsimane' body also regulates the extraction of logging products. Then if the Tsimane' want to sell any logging products extracted from their territory they have to buy a licence to the Superintendance, and this procedure is costly and incites them to

extract woods in an illegal way, which does bring more inconveniences than benefits. Several rumours of corruption run when talking about the Gran Consejo when receiving the grants for the implementation of development project in the Tsimane' territory.

3.3.Livelihood strategies of the Tsimane'

As part of their model specification, Carter and Barrett highlight the importance of two different livelihood strategies with higher or lower returns to assets and yielding to different equilibria. The Tsimane' households can generate their earnings either through a high-return strategy in the sense that these earnings are generated to have more income and to create a surplus in their outputs, or through a low-return strategy where all the earnings generated are used in order to fulfil basic needs and to cope with unexpected events. To decompose the households into two categories, I tried different specifications but all results were quite similar. In what follows I use their earnings and their asset holdings in order to find out two different livelihood strategies. I define as households pertaining to a high-return strategy the ones whose earnings and wealth are in the two upper quintiles at least four years. I have considered four years in the two upper quintiles because I have assumed that a household could face an unexpected event that would decrease its earnings or its asset holdings. From this specification 16 households seem to be engaged in a high-return strategy and 156 households in a low-return one.

Table 7 presents the different characteristic of the households whether they are in a high- or low-return strategy. Next to wealth and earnings, households in a high-return strategy have higher levels of consumption. Even if the differences in total consumption are not really important their consumption of meat they raised are more important. Households in a high-return strategy are larger than households in low-return strategy, their household heads are more educated as well as household members. There are no large differences in the average age of the household head and household members. Another interesting difference between high and low strategies is rice production which is always larger for households in high-return strategy. Corn production is either larger or smaller between high and low return strategies. Households in high-return strategy tend to clear more fallow forest than households in low-return strategies; but they tend to clear the same area of old-growth forest. When looking at their remittances and gifts, no differences can be pointed out which could result from the small number of people receiving remittances or gifts.

4. Definition of an asset index through factor analysis

Carter and Barrett's poverty trap mechanism requires the analysis of an asset accumulation process. The clear goal of the mechanism as explained above is to find out an S-shape curve in the asset accumulation process with a threshold from which household starts accumulating assets in order to switch from a low-return strategy to a high-return one. TAPS collect data on different assets and with some of these assets I have built an asset index using a factor analysis technique.

4.1. Methodology to build an asset index with factor analysis

A factor analysis is *"a statistical technique that consists in representing a set of variables in terms of lower number of hypothetical variables"* (Lawley and Maxwell, 1973; Friel, 2007). The aim of factor analysis is to indicate these unobserved variables, also called underlying factors and to explain that the variables are created out of these underlying factors (Lawley and Maxwell, 1971; Lewis-Beck, 1994). From these underlying factors, the point is to identify common factors source of more than one variable. To do so, factor analysis partitions the variance of each factor into a common variance which is *"the common variance accounted for by the common factor which is estimated on the basis of the variance with other variables"* and a unique variance which is on the other hand *"combination of the reliable variance specific to the variable and a random-error variance"* (Lewis-Beck, 1994). The idea is to keep one common factor which accounts for a larger part of the variance of the variables (Lewis-Beck, 1994; Friel, 2007).

Different types of factor analysis methodology are available. The most common ones are the principal component analysis and the principal factor analysis. The difference between both techniques relies on how the factors explain the variance. When considering the principal component analysis it forces all the components to explain completely the variance of the variables, while the principal factor analysis allows the factors not to explain totally the variance of the variables (Lewis-Beck, 1994; Sahn and Stifel, 2000).

Variables	2002		2003		2004		2005		2006	
	High	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**
Total wealth	**7508.5**	**3566.7**	**5980.4**	**3570.5**	**6455**	**3121.7**	**8301.0**	**4384.5**	**6952.7**	**5114.5**
Animal wealth	1326.1	649.3	864.7	524.7	1773.1	586.6	1946.4	714.3	852.2	786.3
Traditional wealth	1376.5	905.9	1189.1	844.2	1121.9	654.8	1588.9	937.5	1571.3	1136.4
Modern wealth	4805.9	2011.5	3926.6	2201.5	3560	1880.3	4765.7	2732.7	4529.1	3191.7
Total Consumption	**432.8**	**234.8**	**314.9**	**223.9**	**337.4**	**228.7**	**336.0**	**302.7**	**400.4**	**289.7**
Domestic meat	28.7	6.6	18.4	10.9	8.6	8.1	15.4	9.2	23.4	15.4
Staple products	51.5	36.1	51.4	38.0	33.1	21.8	44.9	39.3	56.3	55.2
Wildlife products	230.4	145.2	163.8	129.2	222.6	157.9	179.4	171.8	160.2	122.8
Total earnings	**695.1**	**227.9**	**675.6**	**250.7**	**410.5**	**234.2**	**962.8**	**371.6**	**1013.0**	**433.6**
Sale earnings	367.5	99.6	341.2	116.3	145.1	84.0	490.3	212.9	436.7	178.5
Wage earnings	309.7	105.2	288.0	108.8	227.8	132.8	419.6	125.7	509.5	218.3
Household characteristics										
Household size	8.3	6.4	8.3	6.4	7.7	6.4	8	6.7	7.6	6.7
Age household head	45.1	43.4	43.3	44.7	51.7	44.2	43.5	43.9	48.6	43.4
Education household head	3.8	2.6	4	2.5	3.6	2.3	3.5	2.3	3.9	2.3
Average education for members	2.1	1.6	1.9	1.6	2.0	1.5	1.9	1.6	2.2	1.6
Average age household members	23.4	21.8	17.6	22.3	23.0	22.0	18.7	21.0	20.0	22.0
Agriculture										
Corn production (mancornas)	n/a	n/a	n/a	n/a	88.5	70.9	99.6	77.4	16.8	42.8
Rice production (arrobas)	n/a	n/a	n/a	n/a	119.8	56.4	104.9	84.5	137.4	70.2
Cleared fallow forests (tareas)	6.25	5.1	10.3	6.0	10.4	5.2	8.8	5.7	10.8	6.1
Cleared old-growth forests (tareas)	3.4	4.3	3.2	4.0	3.75	3.3	4.7	4.5	5.2	4.5
Social capital										
Number of gifts received	2.3	1.1	1.9	0.8	1.8	1.1	1.5	1.2	1.1	1.0
Remittances received (bolivianos)	10.9	18.7	5.1	23.9	18.8	2.3	0	1.1	26.0	15.8

Table 7 High- and low-return strategies 2002-2006

The first step is to determine if the variables, here the Tsimane' assets are correlated. To do so, two tests can be done: the Bartlett's test for sphericity and the Kaiser-Meyer-Olkin (KMO) measure of

sampling adequacy. The Bartlett's test consists in measuring the strength of the correlation between variables and its null hypothesis consists in stating that the correlation matrix comes from a sample in which the variables are non collinear. Rejecting the null hypothesis from this test leads to affirm that the variables share at least one common factor that explains their variance. The KMO measure compares the magnitude of the observed coefficients to the magnitudes of the partial correlation coefficients (Lewis-Beck, 1994; Naschold, 2005). If this magnitude is strong enough then the factor analysis is a relevant technique to define an asset index representing the wealth of the households.

The second step consists in estimating the different coefficients required to construct an asset index, as described by Sahn and Stifel (2000), whose form is as followed:

$$AI_i = \hat{\gamma}_1 a_{i1} + \ldots + \hat{\gamma}_K a_{iK}$$

AI_i is the asset index estimated for the i households in the sample, it is a function of their k different assets, a_{ik} whose weights k have to be estimated through factor analysis. What is assumed here is that the ownership of the different assets is explained by a common factor and by a unique element whose variance is not correlated across assets (Sahn and Stifel, 2000).

$$a_{ik} = \beta c_i + u_i$$

And both the common variance c and its coefficient are not observed and must be estimated, which is the aim of a factor analysis. This estimation would lead to construct a matrix of factor loadings that reflect the relationship between the assets and the common factor and the common factor would be derived from this unique matrix of factor loadings (Bhorat et al., 2006).

$$c_i = f_1 a_{i1} + f_2 a_{i2} + \ldots + f_K a_{iK}$$

The welfare is a linear combination of the scoring coefficients f_k of each asset and the asset holdings a_k, then a large factor score would mean that the asset associated to this score is better to explain the differences of welfare between households (Sahn and Stifel, 2003).

And to finally find out the asset index, the factor scoring coefficients are normalised around the mean and the standard variation of each asset (Sahn and Stifel, 2000; Bhorat et al., 2006)

$$AI_i = f_1 \left(a_{i1} - \bar{a}_1 \right) / \sigma_{a_1} + \ldots + f_K \left(a_{iK} - \bar{a}_K \right) / \sigma_{a_K}$$

where f_k are the factor scores for each asset, $\bar{a}_k$ are the mean value of each factor and σ_{aK} the standard deviation. The asset index would be estimated for each household in each year, and the

following subsection illustrates this technique with the Tsimane' data in order to finally analyse the poverty dynamics among the households.

4.2. Choice of the assets included in the asset index

In the definition of this asset index, I use different types of assets representing different categories of capital as explained by Ellis (2001). Asset selection has been done by studying the correlation coefficients between them. I choose only assets that are highly correlated to one another and I obtained the following sample of assets. The physical assets consist in different durable goods such as bike, canoe, mosquito net and radio, these assets are not directly generating earnings through a productive use but they are important in order to increase the welfare of the Tsimane'. Tsimane' with bikes and canoes are more able to go to San Borja and benefit from its amenities. Having a mosquito net is their only way to be protected against malaria. As said before, they communicate by diffusing radio messages which justifies the importance of having a radio. The productive capital is composed of axe, bow, hook, knife, machete, net, rifle and shotgun. These assets are used within their activities, either agricultural (axe, machete, knife) or hunting activities (bow, rifle, shotgun and knife) or fishing (net, hook and knife). Considering their agricultural activities, having an axe could lead to increase their earnings through bigger agricultural plots or through the sales of the trees they cut with the axe. Rifles and shotguns are better weapons to hunt than a bow and the two former ones require additional costs through the purchase of bullets and ammunition. With the same type of analysis, having a net to fish could lead to catch more efficiently fishes than with a hook and a cane. The natural capital is composed of the number of cows they have and the size of cleared forest. Having cows illustrates that household is having cash earnings it could invest in acquiring a cow, while clearing more plots lead to increase earnings through an increase in agricultural production. The proxy for the social capital is the number of gifts received by the households. And the human capital is the number of members speaking Spanish within a household and if any members have mathematical skills within the household.

## a) Bartlett's test and KMO measure to justify the factor analysis

The Bartlett's test for sphericity indicates that the correlation matrix of these different assets is not an identity matrix. Its coefficient is equalled to 0.023 and it is null which allows to reject the null

hypothesis. It seems rational to apply a factor analysis with these assets because the assets to be highly correlated and it can be assumed that a common factor explaining the holdings of these assets do exist. The Kaiser-Meyer-Oklin (KMO) measure of sampling adequacy is large, equal to 0.849. It indicates that the assets share a common factor. The factor analysis is relevant and is a good tool to construct the asset index.

I would assume that only one factor explains the variance of the variables and I would label this factor as welfare. I could start the factor analysis using a principal factor methodology, estimating the factor loadings and factor scores from which an asset index would be built.

b)Factor loadings, factor scores

Figure 2 Scree plot of eigenvalues after the factor analysis
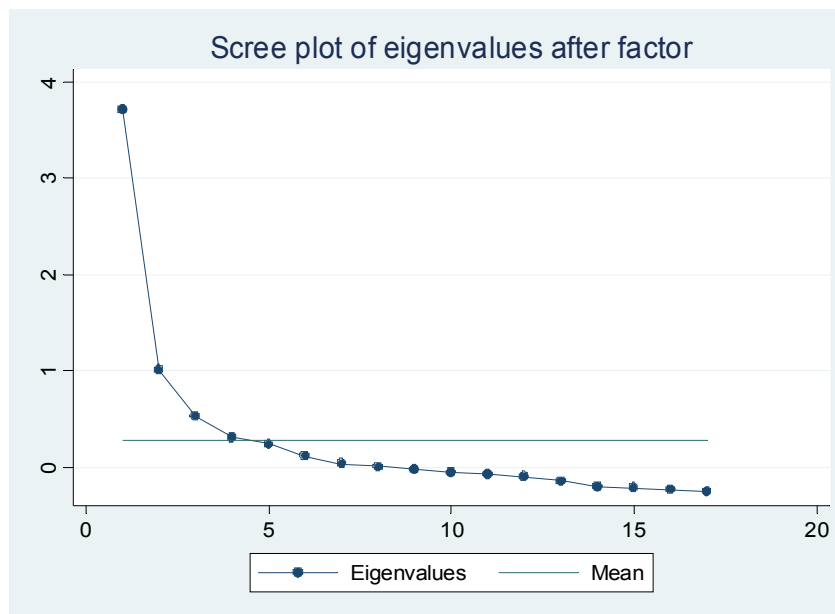
As I assume that only one common factor explains the variance in the asset quantities, I run the factor analysis with STATA specifying that I would retain only one factor. The eigenvalues obtained from the correlation matrix show that two factors explain the variance in the quantities of assets as the first two factors have eigenvalues above 1 and considering the Kaiser criterion I should consider these two factors. The scree plots (Figure 2) show that first two factors are above one, and the Kaiser criterion explains that I should keep all factors whose values are above 1. However because the eigenvalue of the first factor is quite large and the one of the second factor close to 1, and because the first factor explains nearly 80% of the variance in the asset quantities, it is rational and sufficient to take into account only one factor.

The factor loadings for each asset show that the common factor labelled welfare explains positively the variance in each asset. The higher a factor loading value, the better the variance of the related asset is explained by the factor. Here the holdings of machete, mosquito net and knife are better explained by the common factor than the other assets. It seems that as their welfare increases, the Tsimane' would purchase and accumulate these assets than any other assets.

From these factor loadings, the factor scores could be estimated. The Table 8 is obtained and shows that all the assets have a positive effect on the asset index. The relative large weights of machete and mosquito net can be understood as better criteria to differentiate the households according to this asset index, than the size of plot or gifts.

Table 8: Factor scores of the different assets

Variable	Factor scores
Axe	0.14
Bike	0.05
Bow	0.12
Canoe	0.06
Cow	0.03
Hook	0.16
Knife	0.20
Machete	0.26
Mosquito net	0.27
Net	0.08
Radio	0.09
Rifle	0.04
Shotgun	0.07
Size plot	0.09
Gifts	0.03
Spanish	0.04
Maths	0.01

c)Estimation of the asset index

From these factor scores I can define an asset index by normalizing the asset quantities around the mean and the standard deviation. The average values of the asset index in each year are reported in the Table 9. The mean values of the asset index over the period increase. It seems that some kind

of accumulation is happening within the Tsimane' communities. But still it seems that there are some concentrations around 0 which results from the standardisation around 0.

Variables	Obs.	Mean	Std Dev	Min	Max
AI 2002	172	-0.16	1.07	-2.12	3.95
AI 2003	172	-0.14	1.06	-2.05	3.24
AI 2004	175	-0.094	1.07	-1.91	5.47
AI 2005	175	0.12	1.21	-1.53	5.55
AI 2006	176	0.30	1.10	-1.92	4.38

The scatterplot of the asset index versus its lagged value (Illustration 3) and the Kernel density of the asset index (Illustration 4) confirm that there are concentrations close to zero. The scatterplot of the asset index against the lagged asset index does not allow us to reasonably assume that there is a linear relationship between the asset index and the lagged asset index. Different regression

Figure 4 Kernel density of asset index over 5 waves
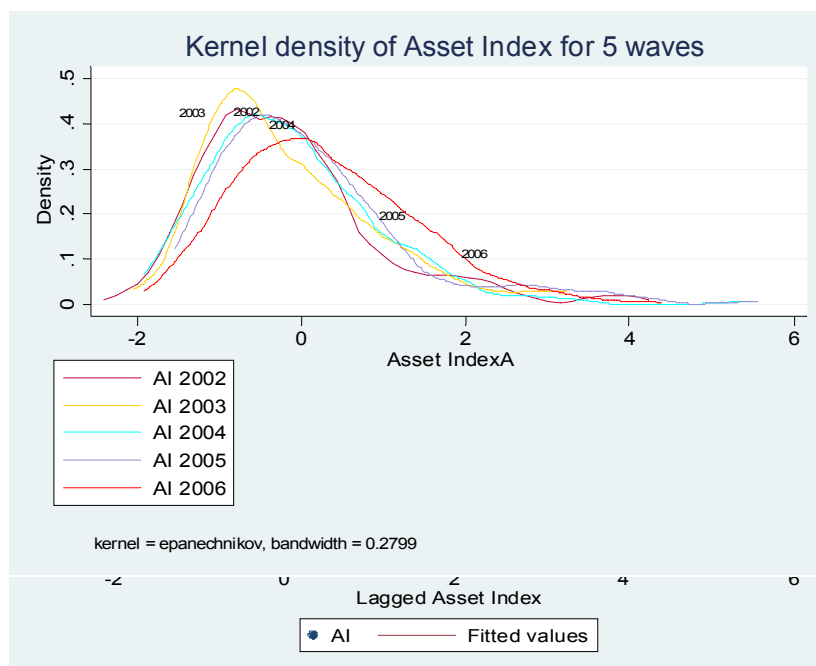
techniques, parametric, nonparametric and semiparametric should be used to demonstrate this relationship.

5. Empirical tests on the existence of poverty trap within the Tsimane'

As concluded previously, the asset index scatterplot does not allow to show if there is any linearity between the asset index and its lagged value which is a condition to obtain an S-shape curve in the asset accumulation with multiple equilibria, both stable and unstable that proves the existence of a poverty trap. Even if at first my idea was to demonstrate an accumulation process for each household or each strategy, the sample size in each strategy, the length of the TAPS survey and some other construction constraints, impede this differentiation. Therefore, I have to assume that households are the same and the asset accumulation process is the same for each household, and I would incorporate household-specific and time-specific effects (Naschold, 2005; Carter and Barrett, 2006). This assumption regarding the existence of an identical pattern of asset accumulation is a major limit to this approach because strategies lead to different uses of the assets and to different asset accumulation preferences.

To deal with non-linearity, different regression techniques are available. Considering parametric regression techniques, a high degree polynomial could be employed to demonstrate the relationship and to find the threshold. I would use nonparametric techniques, and more specifically a locally weighted scatterplot smoother (LOWESS) and penalized splines to estimate the regression of the asset accumulation. Finally like Naschold (200 5), I would use semiparametric regression techniques to demonstrate if the relationship in the asset accumulation process does result from both parametric elements and nonparametric elements. I would use a mixed linear model with penalized splines as a way to estimate a nonparametric function.

5.1. Different parametric, nonparametric and semiparametric regression techniques

a) Parametric estimation using a high-degree polynomial

Different tests on the existence of a poverty trap have used polynomial regression techniques to estimate the asset accumulation process (Ruppert et al., 2003; Barrett et al., 2006). As they did, I would use a fourth degree polynomial regression to estimate the relationship between the change in asset index over four years (2006-05, 2005-04, 2004-03, 2003-02) and their lagged values in 2005, 2004, 2003 and 2002. Using the change in asset index instead of its current value is supported by

the idea that there could be some over/underestimations in asset index values which would bias the model (Naschold, 2005).

$$\Delta AI_{it} = \beta_0 + \beta_1 AI_{it-1} + \beta_2 AI_{it-2}^2 + \beta_3 AI_{it-3}^3 + \beta_4 AI_{it-4}^4 + \Gamma_i Z_i + T_t + \varepsilon_{it}$$

With $\varepsilon_{it} \sim N\left(0; \sigma_\varepsilon^2\right)$ $1 \leq i \leq N$ and $1 \leq t \leq T$

The change in asset index over time is function of a fourth order polynomial of its lagged value AI_{t-1} and also function of household characteristics Z_i that include the age of the household head, the squared age of the household head, the size of the household and the average educational attainment of household members. Then in this polynomial regression, there is a time-specific effect represented by time dummies T_t that take value 1 if time is t and 0 otherwise (Naschold, 2005).

Naschold (2005) clarifies that the age of the household head and its squared value are used to include life-cycle effects in the analysis and that only one single lag in the asset index is possible due to the shortness of the survey period.

b) Nonparametric regression techniques: LOWESS and penalized splines

Contrary to parametric regression, the relationship between the asset index and its lagged value is unknown and must be estimated by fitting a function f through a scatterplot without any assumptions on its functional form (Ruppert et al., 2003; Naschold, 2005). The following function would be estimated.

$$AI_{it} = f\left(AI_{it-1}\right) + \varepsilon_{it}$$

With $\varepsilon_{it} \sim N\left(0; \sigma_\varepsilon^2\right)$ $1 \leq i \leq N$ and $1 \leq t \leq T$

Different estimation techniques could be used to smooth this relationship and I would privilege a smoothing through penalized splines and one through locally weighted scatterplot smoother (LOWESS).

- *Penalized splines*

Adapting the notation from Ruppert et al. (2003) and Naschold (2005), in a spline model, the function f takes the following form

$$f\left(AI_{it-1}\right) = \beta_0 + \beta_1 AI_{it-1} + \sum_{k=1}^{K} u_k \left(AI_{it-1} - \kappa_k\right) + \varepsilon_{it-1}$$

with $\varepsilon_{it} \sim N\left(0;\sigma_\varepsilon^2\right)$, $1 \le i \le N$, $1 \le t \le T$ and $u = \left[u_1,\ldots,u_K\right] \sim N\left(0;\sigma_u^2\right)$

κ represents a knot and there are K number of knots (Ruppert et al., 2003; Naschold, 2005). The penalized spline model can be explained by a mixed model methodology where there is a smoothing parameter which controls the amount of smoothing and penalizes the number of knots. This smoothing parameter is estimated through a restricted maximum likelihood (REML) and the penalized splines are estimated as best linear unbiased predictors (BLUPs) from the mixed model (Ruppert et al., 2003).

- ***Locally weighted smooth scatterplot (LOWESS)***

This is a method for smoothing the scatterplot (Ai_{it-1} AI_{it}) with $i = 1;\ldots; n$. At each value of AI_{it-1}, a fitted value is estimated by running a regression in a local neighbourhood of AI_{it-1} using weighted least squares. The neighbourhoods are defined as a proportion of the total number of observations (Naschold, 2005; Cleveland, 1979). The weight is large if AI_{it-1} close to the fitted value, and small if it is not. Therefore the points close to AI_{it-1} play a large role in the determination of the fitted value of A_{it} while the ones further away play a smaller role (Cleveland, 1979). Then n weighted local regressions would be estimated at each value of AI_{it-1} in order to find the smoothed value of AI_{it} (Naschold, 2005).

c)Semiparametric regression technique

As explained by Ruppert et al. (2003), the semiparametric regression techniques consist in combining both parametric and nonparametric regression techniques (Ruppert et al.,2003). Considering the asset accumulation model I would like to estimate, it consists in adding to the nonparametric specification in equation 6 a parametric element. The semiparametric model could be written as

$$AI_{it} = \beta_0 + \beta_x X_{it} + f\left(AI_{it-1}\right) + \varepsilon_{it}$$

with $\varepsilon_{it} \sim N\left(0;\sigma_\varepsilon^2\right)$, $1 \le i \le N$ and $1 \le t \le T$

This equation is an extension of the nonparametric equation with a parametric element, X_{it} that could either be some household characteristics (education, size of the household, age,...), or time-

dummies taking the value 1 at time t and the value 0 otherwise. These time dummies as well as the age of the household head and its square value, would absorb the time-specific effects, while the household-specific effect would be contained by the household characteristics (Naschold, 2005).

To fit the regression, the nonparametric element would be smoothed using penalized splines through the mixed model as described before (Ruppert et al., 2003; Naschold, 2005).

5.2. Results from these different tests

a) Parametric estimation

I have run the regression on pooled data but introducing either a fixed effect or a random effect. A Hausman test shows that the fixed effect is more appropriate to estimate the change in the asset index. The results reported in the following table show that the lagged asset index has a negative and significant impact on the change in the asset index. All the different lagged asset indices with different power have a negative impact on the change in the asset index. The negative sign of the lagged asset index illustrates the fact that higher the asset index in the previous period, lower the change in the asset index at the current period. The fact that only the lagged asset index at a single power is significant reinforces the idea that the asset accumulation process is quite linear which would lead to a single equilibrium in the asset accumulation.

The life-cycle effects represented by the age of the household head and the squared age of the household head, are significant. However what these two variables show is that the age of the household head has a positive impact on the asset index changes, as the household head becomes older, the asset index varies more from one year to the other, it accumulates less assets than when he was younger but the squared value of the age of the household head shows that this increase would become smaller when household head becomes older. From this estimation, young households would accumulate more assets than older ones but when at a decreasing rate over time.

Table 10: Estimation in the change of asset index through a fourth degree polynomial

Variables	Coefficients
Lagged asset index	-1.071*** (0.08)
Squared lagged asset index	0.05 (0.04)

Cubed lagged asset index	0 (0.02)
Fourth degree lagged asset index	0 (0)
Age household head	0.0449** (0.02)
Square age household head	-0.000449** (0)
Education household head	0.02 (0.03)
Household size	0.280*** (0.03)
Dummy for 2002	0 (0)
Dummy for 2003	-0.189**(0.07)
Dummy for 2004	-0.1 (0.07)
Dummy for 2005	0 (0)
Dummy for 2006	0.170**(0.07)
Constant	-2.902***(0.58)

Observations: 580 Number of hhid: 176
R-squared: 0.6

Standard errors in parentheses (***)p<0.01, (**)p<0.05, (*)p<0.1

The education level of the household has a positive effect on the change in asset index. Even if not significant, this relationship shows that the more educated the household head is, the more he/she would accumulate assets from one year to the other. The effect of education is coherent with the observations in the descriptive analysis as the households engaged in a high-return strategy have higher educational attainment. Household size has a positive and significant effect on the change in asset index which is also coherent with the observations in the descriptive analysis. Larger households need more assets than smaller households and would be incentivized to accumulate assets from one period to another because more household members are supposed to enter the household than leaving it.

Dummy variables for 2003 and 2006 are significant which underline that there is a time-specific effect to this estimation. In 2003, the change 2002 to 2003, would ave been negative while in 2006, the change 2005 to 2006 is positive.

I predict the values of the asset index by predicting first the change in asset index with the previous coefficients. I add to these results the lagged value in assets index to find the value in asset index. The scatterplot of the predicted value of asset index against its lagged value shows that there is no S-shape in the asset accumulation process, there is no Micawber threshold which allow to conclude to a non-existence of a poverty trap. It seems that there is a really smooth concavity in the asset accumulation process which leads to a single equilibrium in the long term.

Figure 5 Scatter plot of the predicted asset index against its lagged value
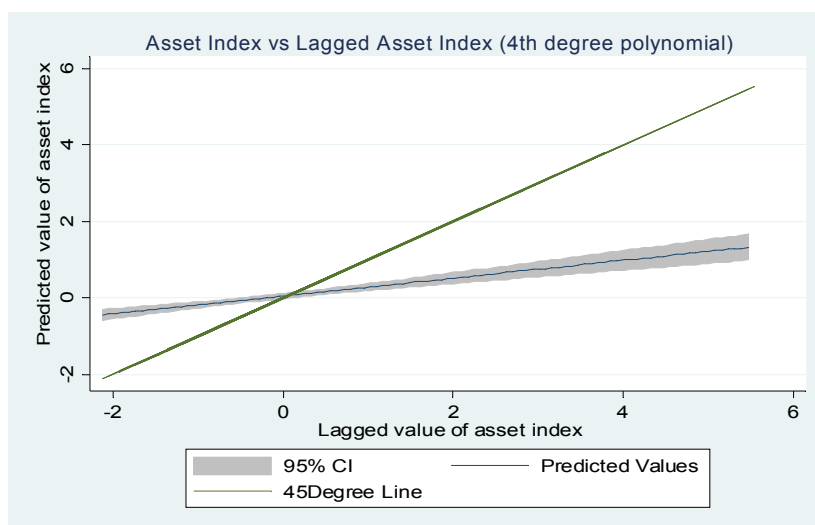
b)Results from nonparametric estimations

- *Penalized splines results*

Estimation by penalized splines through a mixed model shows that there is not an S-shape as required to obtain a poverty trap mechanism (Figure 6). However there is a really smooth concavity in the asset accumulation process leading to conclude that asset accumulation would be larger when small quantities of assets. The asset accumulation would reach a single equilibrium represented on the curves by the intersection point between a 45-degree line and the smoothed curve but reaching this asset equilibrium would take time.

With this asset index, the equilibrium households should reach over time seems to be between [0.9;1.1] point of asset index because the graph shows that the smoothed curve The estimation of

the penalized splines on R using the package SemiPar 1.0 (Wand et al., 2005) specifies that 3.335 degrees of freedom and 35 knots have been used to proceed to this nonparametric regression.

Small degrees of freedom suggest that the asset accumulation is not very non-linear (Naschold, 2005). According to Naschold (2005), both degrees of freedom with the penalized splines estimation are fairly, therefore the dynamic asset accumulation process seems to be quite linear.

I try different degrees of freedom and different number of knots and I obtain the results, only the concavity of the curve is changing.

Figure 6 Scatterplot of asset index against its lagged value with penalized splines (non parametric)

Asset index against lagged value 2002-2006, Nonparametric
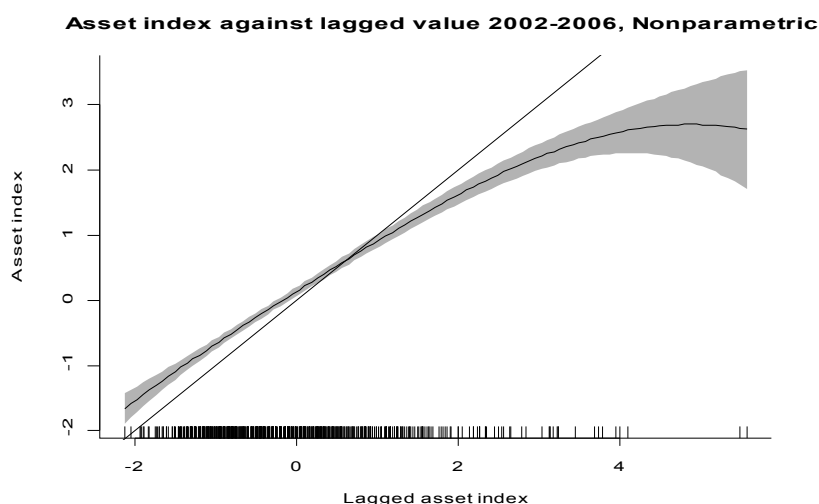
- *LOWESS results*

The estimation of the asset index with a LOWESS used as smoothing parameter gives a curve quite similar to the one obtained with the penalized splines (Illustration 7). There is no S-shape in asset accumulation process, there is no evidence of a poverty trap situation. On the other hand, the concavity of the curve when regressing equilibrium the asset index would reach relies between [0.9;1.1] asset units.

c)Results from semiparametric regressions

I try different specifications starting by considering only the time dummies, then all the time dummies and some household characteristics, but these tests have crashed using the SemiPar 1.0. R package (Wand et al., 2005). Finally two different specifications (the first one presented below and the second one in appendix) have been retained and estimated. Parametric elements for a first specification are the size of the household and the time dummy for 2006, while parametric elements for a second specification consider these same elements completed by the age of the household head, its squared value and the dummy for 2003.

Therefore in the first specification, time-specific effects would only be captured by a time dummy

Figure 8 Scatterplot asset index against its lagged value through non penalized splines (semiparametric)

34
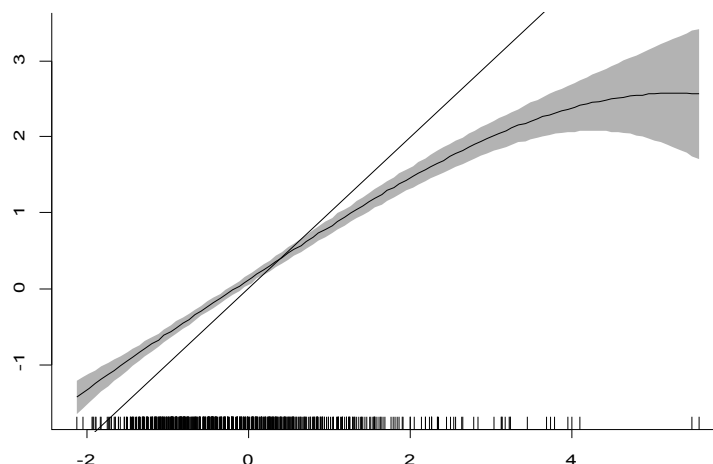
for 2006. In this specification, results report that both the household size and the time dummy have positive and significant effects on the current asset index. To proceed to the smoothing of the lagged asset index through penalized splines, 35 knots have been retained and the degree of freedom is equal to 2.194.

The curve in figure 8 shows that there is no S-shape in the asset accumulation process. There are no multiple equilibria and no Micawber threshold. There is an equilibrium which lies between [0.5;0.7] asset unit. In the long term, Tsimane' households would converge to this equilibrium and would not stay in low levels of poverty.

The second specification presented in the appendix confirms this result, i.e. the absence of a poverty trap mechanism.

Even when introducing more flexibility in the estimation of the asset accumulation process by using semiparametric regression, none of these models show that a poverty trap could arise while considering the Tsimane' assets. All these models have a concave shape with a single equilibrium which varies according to the specification applied between 0.5 and 1.1 asset unit. The concavity of the curves implies that the households with low levels of assets would need more time to reach the equilibrium than the households with higher levels of assets.

6. Conclusion and further implications

6.1. Key findings from the Tsimane' analysis

Instead of finding a S-shape curve in the asset accumulation, all the different regressions have led to find slightly concave curves in the asset accumulation process. Smaller the degree of concavity and smaller the distance between the curve and the 45-degree line, slower the households would move along the asset accumulation path in order to reach the equilibrium.

The parametric regressions show that the lagged asset index, the household size, the age of the household head and its squared value, as well as two time dummies have a significant effect on determining the change in the asset index over time. Predicting the values of the asset index with these coefficients and plotting these values against their lagged value confirm the absence of multiple equilibria in the asset accumulation process which is linear and converging to a single

equilibrium.

The nonparametric and semiparametric regressions present curves where the concavity in the asset accumulation process is identifiable. In all specifications the smoothed curves are below the curves of fitted values. The different regressions show that a single equilibrium exists and households would finally converge to it. The concavity in their asset accumulation curve implies that the initial asset level matters to determine how the households would reach the equilibrium. Households with lower levels of wealth would need more time to reach the equilibrium than households with higher levels of wealth.

Therefore as the scatterplots in the analysis show that most of the households are concentrated in low levels of asset accumulation and really few of them have higher levels of wealth, the Tsimane' still need time in order to escape poverty. The different shocks, both idiosyncratic or covariant, they would face, would even raise the time they would need to reach the equilibrium if their wealth levels are pushed further down.

6.2.Comparisons between this test and other poverty trap tests

a)A single asset or an asset index

A first element consists in the type of assets used in the different studies. Both Lybbert et al. (2004) and Barrett et al. (2006) test the poverty trap mechanism on pastoralist households whose main asset is their livestock. More precisely, their analysis of the asset accumulation process relies only on the accumulation of livestock, excluding any other types of assets. What is interesting to note and what Lybbert et al. (2004) remark is that livestock is not only an asset but fulfils many essential roles in the livelihood of the pastoralists. Besides being a source of wealth, livestock is usually used as a source of food, as a provider of services like transport. Livestock holdings are also an *"object of status"* and they *"regulate the ecosystems"* (Lybbert et al., 2004). By their own nature, the livestock fulfils much more essential needs than the assets in the asset indices do.

The assets in the asset indices are much more diversified, with different functions and different assets can fulfils the same function. On the other hand, the pastoralists rely largely on the livestock and they do not seem to have any other means to perform these functions. Their total reliance on livestock explains that the loss in even a small number of livestock leads to a situation where as

they do not have any survival means, they would be ensnared in this situation without knowing how to escape it. The articles that have not concluded on the existence of a poverty trap mechanism develop specifications similar to the Tsimane' one where instead of considering a single asset, asset indices covering wide range of assets have been constructed. Naschold (2005) has built an asset index encompassing different asset holdings which are less subject to sudden drops than could be only the livestock holdings. Barrett et al. (2006) constructs an asset index to study the Malagasy households whose main activity is rice cultivation which requires more diversified assets.

b)Mono activity or wide portfolio of activities

A second element linked to the first one relies on the fact that these articles have considered households with similar activities. In Lybbert et al. (2004) and Barrett et al. (2006) the households have one main activity which is raising cattle for the milk. On the contrary, the Tsimane' households have at their disposal a wide range of activities they use either as source of income or as an insurance mechanism. This mono-activity depending mainly on livestock to generate livelihood explains why a poverty trap could arise as they do not have any other activities to generate their livelihood. On the other hand, the Tsimane' households with their wide range of activities seem to have more possibilities to engage themselves in one activity instead of the other, change from one activity to another according to their needs and the labour opportunities.

c) Internal characteristics of the sample

Adato et al. (2006) has not studied pastoralists households but South-African households with different activities and assets . They develop an asset index regrouping four types of assets and the asset index accumulation process leads to multiple equilibria. Their study is quite similar to the Tsimane' one and the only difference that could explain why they have found the evidence of a poverty trap mechanism could rely on the fact that the South-African households in their sample present more different characteristics from one another than the Tsimane'. The Tsimane' population is much more homogeneous than other populations studied by Adato et al. (2006). The Tsimane' even after differentiating in terms of strategy and wealth remain quite homogeneous while the South-African households have more diversified patterns. The homogeneity of the

Tsimane' sample is visible through the analysis of the asset index while using the dummy variables for any types of assets and durable goods. Really few households are poor in terms of the asset index, the majority of the households report holding the asset. Adato et al. (2006) in their asset index include assets and household characteristics that vary according to each household.

d)Short time period or long time period

The last element justifying why Lybbert et al. (2004), Barrett et al. (2006) and Adato et al. (2006) have proved the existence of a poverty trap could be the time period. Both articles use data from surveys that cover at least ten years while the TAPS data in the analysis cover only three years. Then asset accumulations and poverty dynamics seem more relevant over longer period of time than shorter ones which could explain why they find multiple equilibria in the asset accumulation.

Similarly to the Tsimane' study, Naschold (2005) uses only short period of time data, up to five years which could explain why no real asset changes could occur and why he does not find any poverty trap (Naschold, 2005).

6.3.Policy implications and further points to develop

Failing to prove that a poverty trap does exist among the Tsimane' households does not imply that they are ready to escape the low levels of economic development in which they rely. The concavity of their asset accumulation path suggests that reaching a higher equilibrium for the poorer households is a long process. Then different measures are required to try to accelerate their asset accumulation and improve their well-being. A striking element while doing the fieldwork was that all the households are cultivating the same type of crops without cooperating. Better organization at the village level leading to create cooperatives and more bargain power when dealing with the traders could be a way to incite the households to become more productive in their agricultural activity. The high diversification of their livelihood without being specialized in any activity in order to generate higher earnings when becoming more productive could explain why the Tsimane' households are still really poor and would reach higher levels of welfare through a long period of time. When doing only one activity, most of the households in the sample do it in order to fulfil their basic needs, so it might be interesting to help them developing such activities and cooperation.

Also different elements could be added to this analysis to improve it and capture other effects. The idea could be to focus more on the activities in order to understand the rationality that leads one household to undertake one type of activity as to generate an income while other would use the activity as a way to face unexpected events. Their vulnerability seems to keep them into non-productive activities, therefore it would be interesting to identify if they have any other insurance mechanisms that could replace the activities as insurance mechanisms. The rationality would be to find a way to separate the activities from the insurance mechanisms inciting the households to engage themselves into more productive activities that would reduce their vulnerability and increase their well-being. It might be also interesting to study how the current changes in the availability of game, the depletion of medicinal plants would lead the Tsimane' households to engage themselves more in wage or sale activities in order to afford the meat and Western medicines they need. These losses are supposed to increase their vulnerability and their dependence on the market.

Appendix

A. Bartlett's test and KMO measure

```
Determinant of the correlation matrix
Det= 0.023
Bartlett test of sphericity
Chi-square=3242.965
Degrees of freedom = 136
p-value =  0.000
H0: variables are not intercorrelated
Kaiser-Meyer-Olkin Measure of Sampling Adequacy
KMO =     0.849
```

B. Factor loadings coefficients

```
Factor analysis/correlation                    Number of obs   =      870
    Method: principal factors                  Retained factors =        1
    Rotation: (unrotated)                      Number of params =       17

    --------------------------------------------------------------------
      Factor  |   Eigenvalue   Difference       Proportion   Cumulative
    ----------+---------------------------------------------------------
      Factor1 |     3.71410      2.70345           0.7959       0.7959
      Factor2 |     1.01066      0.47873           0.2166       1.0125
      Factor3 |     0.53193      0.22753           0.1140       1.1265
      Factor4 |     0.30440      0.06685           0.0652       1.1917
      Factor5 |     0.23755      0.11913           0.0509       1.2426
      Factor6 |     0.11842      0.07890           0.0254       1.2680
      Factor7 |     0.03952      0.03596           0.0085       1.2765
      Factor8 |     0.00357      0.02701           0.0008       1.2772
      Factor9 |    -0.02344      0.02751          -0.0050       1.2722
      Factor10|    -0.05095      0.02502          -0.0109       1.2613
      Factor11|    -0.07597      0.02074          -0.0163       1.2450
      Factor12|    -0.09671      0.04845          -0.0207       1.2243
      Factor13|    -0.14516      0.05694          -0.0311       1.1932
      Factor14|    -0.20210      0.00992          -0.0433       1.1499
      Factor15|    -0.21201      0.02055          -0.0454       1.1044
      Factor16|    -0.23256      0.02228          -0.0498       1.0546
      Factor17|    -0.25484           .           -0.0546       1.0000
    --------------------------------------------------------------------
    LR test: independent vs. saturated: chi2(136) = 3246.72 Prob>chi2 = 0.0000
```

Factor loadings (pattern matrix) and unique variances

```
    --------------------------------------
      Variable |  Factor1 |   Uniqueness
    -----------+----------+---------------
           axe |  0.5847  |     0.6581
          bike |  0.3118  |     0.9028
           bow |  0.5488  |     0.6988
         canoe |  0.3286  |     0.8920
           cow |  0.2032  |     0.9587
          hook |  0.6264  |     0.6076
         knife |  0.6825  |     0.5342
       machete |  0.7359  |     0.4584
   mosquito net|  0.7432  |     0.4477
           net |  0.4197  |     0.8238
         radio |  0.4404  |     0.8061
         rifle |  0.2467  |     0.9392
       shotgun |  0.3764  |     0.8583
     size plot |  0.4562  |     0.7919
         gifts |  0.1662  |     0.9724
       Spanish |  0.2399  |     0.9424
         maths |  0.0810  |     0.9934
    --------------------------------------
```

C.Mean values of assets used in the asset index

```
     Variable |        Obs        Mean    Std. Dev.        Min         Max
--------------+--------------------------------------------------------------
          axe |        875    1.386286    .9788586          0           6
         bike |        875    .3565714    .7538989          0           5
          bow |        875       1.616    1.381049          0          11
        canoe |        875    .4685714    .6881522          0           4
          cow |        875    .4822857    2.088016          0          24
--------------+--------------------------------------------------------------
         hook |        875    5.469714    3.577508          0          26
        knife |        875    3.505143    2.285345          0          18
      machete |        875    3.506286    1.963254          0          15
  mosquito net |       875    4.193143    2.281244          1          15
          net |        875    .7954286    1.016107          0           5
--------------+--------------------------------------------------------------
        radio |        875    .8902857    .8686423          0           6
        rifle |        875    .5085714    .5962178          0           3
      shotgun |        875    .4228571    .5594445          0           3
    size plot |        875    10.10131    7.528318          0         100
        gifts |        880      1.1375    1.303868          0          10
--------------+--------------------------------------------------------------
      Spanish |        880       1.225    1.141547          0           7
        maths |        880    .9227273    .2671755          0           1
```

D.Second test with semiparametric regression

This test includes as parametric elements the age of the household head, its squared value, the size of the household and two time dummies for 2003 and 2006. Only the household is significant and has a positive effect on the asset index. The asset accumulation curve does not have a S-shape but seems linear with a smooth concavity. An equilibrium lying between [0.2;0.5] seems to exist and Tsimane' households should converge towards it over time (Illustration 9).
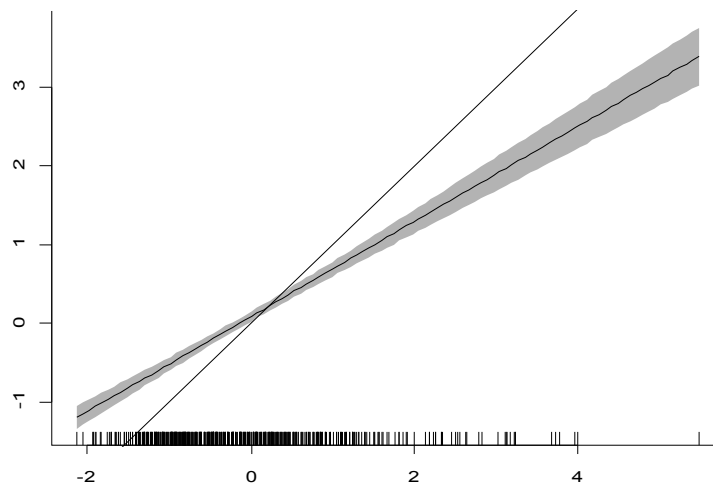
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