Household Investment, Heterogeneous Productivity, and Poverty Dynamics: Theory and Evidence from Kagera, Tanzania*

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Abstract

Agricultural households use assets not only for production as a source of income generation but also for protecting consumption from negative economic shocks. We show a model of household dynamic decisions on investment in agricultural productive assets under credit constraints and non-convex production technology. We test and estimate the model with data from Kagera, Tanzania in order to show its usefulness for quantifying the relative magnitude of potential determinants of poverty dynamics and effectiveness of counter-factual policies for poverty alleviation. We ask whether there is a poverty trap and a threshold in dimension of assets and productivity which determines household's forward-looking behavior and welfare status in the future.

Keywords: asset accumulation, land, livestock, human capital, consumption smoothing, structural estimation, counter-factual simulation

JEL classification: D9, O12, Q12[1]

1 Introduction

Most development economists would like to know why some households remain in poor economic condition and how society can solve this problem. Poverty dynamics is equivalent to change in income generating power and we focus on endogenous accumulation of productive assets as the source of income generation rather than exogenous change

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[1] D9: Intertemporal Choice and Growth. O12: Microeconomic Analyses of Economic Development. Q12: Micro Analysis of Farm Firms, Farm Households, and Farm Input Markets.

in income generating power. The previous literature show that under non-convex production technology and credit constraints, a poverty trap and threshold can exist. The threshold determines household forward-looking behavior and thus welfare status in the future. The threshold can exist in dimension of everything which affects production and intertemporal allocation of income, which includes unobserved productivity. Thus, two households' dynamic decisions and behaviors such as investment can be opposite even their observed characteristics are similar if one's unobserved productivity locates in the opposite side of the threshold to the other's. The previous empirical papers have not taken this possibility carefully and assumed all households' behaviors are identical after controlling heterogeneity in observed household characteristics. We focus on the possibility of the threshold in dimension of productive assets and unobserved productivity and ask whether this phenomenon exists in a data by constructing household investment model which accommodate heterogeneous productivity and fitting the model to data on agricultural households in Kagera, Tanzania (subsample of Kagera Health and Development Survey (KHDS)).

Our model is simple and based on household's investment decision under credit constraints. We model household's economic problem as follows: Given its agricultural productive assets such as land, livestock, human capital and its productivity, a household engages in risky agricultural production. After agricultural income is realized, the household allocates its income into consumption and investment in agricultural productive assets given budget and credit constraints, and stochastic structure of asset accumulation. In the model, there are 6 potential factors of poverty: (1) credit constraint, (2) risk and volatility in income and return to investment, (3) low development of exogenous economic condition, (4) initial low asset and income, (5) ability to cope with negative income shock by dis-saving of productive assets, and (6) productivity. By recovering underlying economic structure and household behavioral parameters based on the model and data, we can implement counter-factual policy simulations and obtain their policy implications. Empirical results provide relative quantitative magnitude of obstacles against escaping from poverty among the six potential factors above. For example, how effective government transfer or insurance is depends on stochastic structure of income risk, dynamic value of productive asset and how elastic households respond to government policies.

Empirical method is a dynamic programming structural estimation. First, we estimate production function, unobserved productivity, and transition probability functions from the data. Second, we compute optimal investment function given unknown parameter values of utility function and investment cost function and estimated production and transition probability functions. Third, we search parameter values which explain observed data best in the sense that computed optimal investment is the closest to observed investment in the data. Based on these estimates, we implement counter factual policy simulations such as providing government transfer, insurance, credit in order to quantify relative magnitude of potential determinants of poverty dynamics and relative effectiveness of the policies for poverty alleviation.

Section 2 reviews related previous studies. Sections 3 and 4 introduce our model and data, respectively, and discuss our focus and limitations of the model and data. Empirical methods and estimates are described in section 5. Section 6 shows how well our estimated model fits the data and then implements counter-factual simulation in order to quantify relative magnitude of potential determinants of poverty dynamics and effects of policy interventions.

2 Previous studies

Some previous papers try to study poverty dynamics by utilizing panel data over a decade. Most of them are based on descriptive statistics and reduced-form empirics and study causality and qualitative relationship. We can say that this literature is in the initial stage of study in the sense that most papers try to obtain clues about what is going on in the data. However, if we make explicit what is a background model and study data based on the model even in the initial stage of study, we can obtain further insights on poverty dynamics. If we do not specify a model, even after we have estimates on policy inputs and outputs, channels of causality is still in a black box. On the other hand, if we specify a model, we can test our hypothesis on channels or mechanism with data. Furthermore, we would like to know not only qualitative relationship (causality) but also quantitative relationship among potential factors on poverty dynamics. Empirical studies based on a structural model allow us to obtain the quantitative relationship among multiple factors by recovering underlying structure and implementing counter factual simulations. We not only test the model but also quantify the model itself and at the same time we obtain policy implications on multiple factors of poverty dynamics. Note that we need to recover the underlying structure which is robust to policy changes if we would like to obtain relative magnitudes of multiple policies' effects on poverty dynamics.

From this point of view, there are two important previous papers, Rosenzweig and Wolpin (1993) and Fafchamps and Pender (1997). They model household investment decision in order to study why some households do not invest in profitable agricultural technologies and how important this behavior is on their poverty dynamics. Their contribution is two-fold. First, they make explicit what is a mechanism of poverty dynamics/traps, more particularly, they shows a poverty trap due to non-convex production technology and credit constraints. Second, they quantify the magnitude of potential determinants by fitting the model to data and implementing counter-factual simulations.

Rosenzweig and Wolpin (1993)'s empirical methods consists of two main steps. As the first step, they estimate the simple farm profit function with bullock and pump sets as inputs. Then, based on these estimates of profit function parameters, they estimate remaining structural parameters such as utility function parameters and unobserved production costs. Based on these structural parameter estimates, they show their two main simulation results: (1) The counter-factual provision of actuarially fair weather insurance would have little effect on farmers' welfare; (2) The counter-factual receipts of assured stream of income have a substantial positive effect on agricultural production efficiency and output. Note that their results do not necessarily imply that credit constraint and low income is major obstacles against investment and escape from poverty but production risk is not since counter-factual recipients of income relaxes household budget constraints but counter-factual provision of actuarially fair insurance does not.

Fafchamps and Pender (1997) focus on non-divisibility and irreversibility of tube well investment and use a method which is similar to Rosenzweig and Wolpin (1993)'s method.

Their counter factual simulations are (1) the return to well is cut by half, (2) allow borrowing, and (3) higher return to liquid wealth. Their results imply that (1) credit constraint is a major obstacle for poor to invest in non-divisible but profitable tube-well; (2) irreversibility of the investment is an additional minor deterrent for poor to invest.

Dercon (1998) studies investment in cattle in rural Shinyanga, Tanzania[2]. Although his model is richer and more complicated in the sense that it has not only investment decision but also decisions on labor allocation among safe and risky farming and cattle rearing, and decisions on hiring labor and renting oxen, the main qualitative result is the same as the two previous paper's result: poor households do not invest in more profitable but more risky productive asset since they cannot finance lumpy investment and they need to have less-risky income to prevent their consumption from falling below the subsistence level. His main results is based on numerical simulations and he does not fit the model to the data as the two previous papers do, maybe because of too small sample size of his data.

Barrett, Carter and Ikegami (2008) and Carter and Ikegami (2007) extend the model of investment and poverty dynamics by allowing heterogeneity in ability or productivity among households and explore what kinds of poverty dynamics we observe based on numerical simulations. Like the two papers above, these paper also have a model of a poverty trap in which main causes of the poverty trap are non-convex production technology and credit constraints. Their main result is that the difference in ability/productivity generates different poverty dynamics: high ability households will not remain in poverty regardless initial asset levels but low ability will do. Whether moderate ability households will end up in poverty depends on initial asset levels and realizations of economic shocks. They also show that severeness and persistence of poverty in a society depends on distribution of ability, initial asset levels and the structure of risk in the society. One remaining important question in the literature is how important each of potential determinants of poverty dynamics in data, especially whether the main cause of heterogeneity in poverty dynamics is initial asset, ability, or realization of shock. This aspect of poverty dynamics is also an empirical question.

These paper's contribution to the literature of poverty dynamics is two-fold. First, these papers show a basic model of poverty trap. Some of development researchers are implicitly assuming poverty trap and vulnerability generated by risk and shock but their background models are ambiguous. This asset-based model can be a basic model for them by specifying particular assets or state variables in order to apply the model to their focus. Second, they show the importance of incentive effects or forward-looking decisions when we would like to measure poverty and design effective poverty alleviation policies.

One may claim that how important these papers and their contributions is an empirical question by the following three reasons. First, the importance of incentive effects

[2]Shinyanga region shares the border with Kagera to the North. Since Shinyanga region is semi-arid and the main crops grown are cotton, different type of sorghum and millet, maize and sweet potatoes (Dercon (1998) p.4), it is similar to the Southern part of Kagera (annual crop zone) in this aspect. However, the two regions are different in the following two aspects of livestock: 49% of households own cattle (Table 2) and some of them use oxen for ploughing (p.4) in Dercon (1998)'s data. On the other hand, based on the data we use, in the Southern part of Kagera only 15% of households own cattle and they do not own oxen for ploughing.

or forward-looking decisions is partly due to their assumptions which can generate a poverty trap, more particularly, assumptions of credit constraints and non-convex production technology. Relevancy of these assumptions is an empirical question. Second, in reality, assets and state variables which are closely related to poverty dynamics cannot be in one-dimension as in their model. Thus, if we would like to obtain quantitative implications based on the model and data, we need to show that it is feasible to obtain quantitative results although households are solving more complicated multi-dimensional decision problem. Third, they omit other potential important determinants of poverty dynamics such as exogenous changes in economic structure and interaction among households and focus on individual household's asset accumulation but how important each determinant compared to others is an empirical question.

We would like to provide answers to the first two of these three questions in this paper and show that household invest model and structural approach on poverty dynamics is useful even in order to obtain qualitative policy implications from data.

The expected contribution of this paper as main differences from the previous papers is two-fold. First, we allow heterogeneity in productivity among households and quantify its importance on poverty dynamics compared to other potential determinant of poverty dynamics based on the model and data. If there is poverty trap for some households, the results in Barrett et al. (2008) and Carter and Ikegami (2007) apply, more particularly, it is important to take heterogeneity in productivity into accounts since investment decision, future welfare status and desirable policy intervention are different among households with different productivity. Even if not, the speed of asset accumulation is different among households due to heterogeneity in return to assets and thus future welfare status and desirable policy are different and we quantify the magnitude of these differences.

Second, we quantify the effects of demographic change on poverty dynamics. More particularly, the number of household members is included in the model as one of assets although it is not household's control variable[3]. In the data, the number of household members changes over a decade due to HIV/AIDS and member's leave for marriage and household split. This change affects change in other assets (land and livestock) over a decade through inheritance and transfer when next generation in a household leaves the original household and starts his/her own new household and agricultural production. We quantify the effects of risk and shock in transition of this asset itself (the number of household members as human capital) and transition of other assets (land and livestock) due to change in this asset on poverty dynamics.

3 Model

We introduce our model in this section. Discussion on our focus and relevancy of the model for studying poverty dynamics based on the data is located in the following section.

Household j has time-invariant productivity α_j and assets $k_{jt} = (k_{ljt}, k_{cjt}, k_{njt})$ where k_{ljt} is land in hectare, k_{cjt} is livestock in monetary value, and k_{njt} is the number of house-

[3] Foster and Rosenzweig (2002) focus on household division and their model includes the choice of leaving original household and forming a new household in choice set of each household member. One might be interested in that investment in health affects probability of death, that is, stochastic transition function of the number of household members. We do not focus on these topics in this paper.

hold members[4]. Given assets and productivity, the household engages in agricultural production and obtains agricultural income $y_{ajt} = f(\alpha_j, k_{jt}, \epsilon_{yajt})$ where ϵ_{yajt} is agricultural production shock[5]. The household has exogenous non-agricultural income y_{najt}. Given income and assets, the household allocates its income into consumption c_{jt} and investment $i_{jt} = (i_{ljt}, i_{cjt})$ where i_{ljt} and i_{cjt} are investments in land and livestock respectively. The cost of land investment is represented by land investment cost function $e_l(i_{ljt}, p_{ilt}, \epsilon_{iljt})$ where p_{ilt} is price of land per hectare and ϵ_{iljt} is unobserved land investment cost shock. ϵ_{iljt} captures the stochastic event where a household can buy (or sell) land at moderate cost only when there is another household in the neighborhood who would like to sell (or buy) the land. On the other hand, the cost of livestock investment/disinvestment is defined to be just monetary value of livestock based on the assumption that livestock market is more active and developed than land market. The household divides total consumption c_{jt} evenly to each household member, that is, member m's consumption c_{jmt} is equivalent to c_{jt}/k_{njt}. The household obtains total utility, which is defined as the summation of each member's utility, that is, $u(c_{jt}) = \sum_{m=1}^{k_{njt}} \tilde{u}(c_{jmt})$ where $\tilde{u}(c_{jmt})$ is member m's individual utility.

Assets at the next period is determined by asset transition functions: $k_{lj,t+1} = k_{ljt} + i_{ljt} + \epsilon_{kljt}$, $k_{cj,t+1} = k_{cjt} + i_{cjt} + \epsilon_{kcjt}$, and $k_{nj,t+1} = k_{njt} + \epsilon_{knjt}$ where ϵ_{kqjt}, $q = l, c, n$ are asset transition shocks. Note that although we do not include the decision on investment in human capital k_{njt} in the model, we accommodate birth, death, leave and arrival of household members by ϵ_{knjt} in the model. We assume that each household takes change in the number of household members as exogenous random event instead of endogenous decision and knows probability density distribution function of ϵ_{knjt}. Based on its expectation of accumulation transition of numbers of household members, the household decides intertemporal allocation of income into consumption and investment in land and livestock.

We are assuming that there is no credit market, asset rental markets (land and livestock), labor market, and insurance market as the extreme simplification of incomplete markets. Note that we are assuming that land and livestock are only two assets which households can accumulate and use for protecting consumption from income shock and asset accumulation shock, for example, households do not have financial asset. Inheritance and transfer of asset to other households are treated as asset accumulation shock.

This household dynamic decision problem is represented by the following utility max-

[4]Subscript l is from the initial of land. Subscript c is from the initial of cattle but k_{cjt} includes not only cattle but also other livestocks such as chicken and goat. Subscript n for number of household members follows conventional usage in economics. We can relax the assumption of time-invariance productivity but we need to decide whether we include decision on investment in productivity in the model or not. Even if we decided not to include it, we need to define (exogenous) transition function of productivity and figure out how to estimate it.

[5]Note that we do not distinguish covariate agricultural production shock from idiosyncratic agricultural production shock although how to protect households from covariate shock by government policy intervention is an important topic. It is just because we have not figured out how to estimate covariate shock separately from productivity α_j.

imization problem at period τ:

$$\max_{i_{ljt}, i_{cjt}} \mathrm{E}_\tau \sum_{t=\tau}^{\infty} \beta^{t-1} u(c_{jt})$$

$$\text{s. t. } c_{jt} + e_l(i_{ljt}, p_{ilt}, \epsilon_{iljt}) + i_{cjt} \leq f(\alpha_j, k_{jt}, \epsilon_{yajt}) + y_{nat} \tag{1}$$

$$k_{lj,t+1} = k_{ljt} + i_{ljt} + \epsilon_{kljt} \tag{2}$$

$$k_{cj,t+1} = k_{cjt} + i_{cjt} + \epsilon_{kcjt} \tag{3}$$

$$k_{nj,t+1} = k_{njt} + \epsilon_{knjt} \tag{4}$$

$$\text{where } t = \tau, \tau+1, \cdots, \infty$$

$$\text{given } \alpha_j, k_{j\tau}, \epsilon_{yaj\tau}, y_{naj\tau}, p_{il\tau}, \epsilon_{ilj\tau} \tag{5}$$

where $u(c_{jt}) = \sum_{m=1}^{k_{njt}} \tilde{u}(c_{jmt})$ and $c_{jmt} = c_{jt}/k_{njt}$. Equation (1) is the budget constraint at period t and note that we are omitting credit from the model[6]. The model has the following eight potential determinants of poverty dynamics (1) credit constraints, (2) production risk and shock (ϵ_{yajt}), (3) asset accumulation risk and shock $\epsilon_{kjt} = (\epsilon_{kljt}, \epsilon_{kcjt}, \epsilon_{knjt})$, (4) non-convex production technology $f(\alpha_j, k_{jt}, \epsilon_{yajt})$, (5) lumpiness of investment, (6) initial low asset and income, (7) non-agricultural income y_{najt}, and (8) productivity α_j.

Non-agricultural income y_{najt} affects poverty dynamics through the income effect: the more total income is, the larger investment is. There is another path through which it affects poverty dynamics. Since non-agricultural income is assumed to be risk-free income source, the more non-agricultural income is, the less a household has to worry about income fluctuation and consumption smoothing and thus the household will invest more.

4 Data

What we have to emphasize is that we are not trying to show the poverty dynamics of all household in Kagera, Tanzania. Our focus is poverty dynamics of rural agricultural households in Kagera, Tanzania. The reasons why we focus on particular households are (1) this paper is our first try to analyze asset-based poverty dynamics in Kagera, Tanzania and we need to focus on homogeneous households who solve the simpler dynamic problem than other households, and (2) due to the limitation of data.

Section 4.1 briefly describes the original data and most of selected households are severely affected by HIV. This is not the reason why we chose the data. The reasons why we chose the data are that (1) KHDS traces out households over a decade and (2) most of households are homogeneous as rural agricultural households. We discuss what subsample of the data we are focusing in Section 4.2 and then we discuss what aspects of behaviors

[6] If we would like to relax this assumption of no credit market, a straightforward way of extending the model is introducing the debt b_t and the budget constraint would become the following:

$$c_{jt} + e(i_{ljt}, p_{lit}, \epsilon_{iljt}) + i_{cjt} + (1 + r_t)b_{jt} \leq f(\alpha_j, k_{jt}, \epsilon_{yajt}) + y_{najt} + b_{j,t+1}$$

$$b_{j,t+1} \leq \gamma_t k_{jt} \tag{6}$$

where r_t is interest rate at period t and equation (6) is the credit constraint at period t and γ_t is a positive number. The debt $b_{j,t+1}$ is household's choice and we need the non-Ponzi game condition too.

of the selected households we are focusing in Section 4.3. The details on how we construct the data set for our analysis from the original KHDS data are located in Appendix A.

4.1 The Original Data

We use Kagera Health and Development Survey (KHDS), Tanzania. KHDS has 5 waves of survey. The first 4 waves were collected between 1991 and 1994 and the last wave (wave 5) was collected in 2003. Wave 1 and wave 5 are annual survey and asked households about the past 12 months. On the other hand, wave 2, 3, and 4 are half-year survey and asked households about the past 6 months.

KHDS is not a survey which represents Kagera or Tanzania. The original objective of the survey (in 1991-1994, wave 1-4) was to study effects of HIV on households. Kagera is one of the regions in Tanzania where households are severely affected by HIV. When investigators chose households in Kagera, first they chose clusters (places) and then chose households in each cluster. Each cluster is categorized into one of four agronomic zones: (1) tree crop zone, (2) riverine zone, (3) annual crop zone, and (4) urban zone and each zone has 10-15 clusters. 26 out of 51 clusters are selected from the wards (administrative area that is smaller than districts) where adult mortality rate is very large (more than 90 % quintile) and the remaining 25 clusters are selected from the remaining wards with smaller adult mortality rates. At each cluster, each household is categorize as "sick" if the household had either an adult death due to illness in the past 12 months, and adult too sick to work at the time of survey, or both. If not, the household is categorized as "well". At each cluster, 14 households were randomly selected from the "sick" households and 2 households were randomly selected from the "well" households. Total 816 households (= 16 households times 51 clusters) were enumerated in 1991 (wave 1). See World Bank (2004) for the details on wave 1 to 4.

The data is very unique in the sense that investigators in 2003 (wave 5) try to trace out all household members in 1991-1994 (wave 1 to 4). Households split over a decade and the number of households increased from 816 to 2,774 between wave 1 and 5. See Beegle, de Weerdt and Dercon (2006a) for the detail of wave 5.

4.2 focus and limitations when choosing subsample of households

We focus on poverty dynamics of rural agricultural households. Furthermore, we focus on decision on investment/disinvestment in land and livestock and risk and shock in agricultural production and accumulation of land, livestock and household members as main determinant of poverty dynamics. We think this focus is the first step to analyze poverty dynamics structurally based on household model. We understand that we are ignoring endogeneity of all of other investment and dynamic decision such as investments in other agricultural physical capital (machine and tool), human capital, and social capital, crop choice, technology adoption (fertilizer and high yield varieties), occupational choice, migration, leaving from household, marriage, sending and receiving transfer, and making children. There are some problems or limitations in the method we have to deal with. However, we cannot model all of dynamic decision and investment because of curse of dimensionality. Also, we need homogeneity in households in the sense that households we are analyzing the same or similar dynamic programming problem. In the remaining of this subsection and next subsection, we discuss what subsample of data we use for the analysis and why we think our model is appropriate for analyzing poverty dynamics of the household in the subsample and limitation of our model.

Wave 5 of KHDS (in 2003) tracks households and their members who emigrated between 94 and 03. However, investigators do ask those emigrated households about their agriculture less than non-emigrated households in order to reduce work load for tracking phase and thus data on agriculture are much less complete compared to non-emigrated households. Since data on agricultural outputs and productive assets for emigrated households are not collected, we simply drop emigrated households from our analysis. Unfortunately, the number of emigrated household are large: there are 1,413 emigrated households out of all 2,774 households in 2003. However, we should not say 51% (1,413 out of 2,774) households emigrated. First, these 2,774 households in 2003 includes split households from the original 919 households in 1991 and 1992. Second, 540 out of 1,413 emigrated households emigrated to nearby villages. If we take household unit in 1992, total 830 households are resurveyed in 2003[7]. Out of them, 733 households have at least one new household unit (household unit in 2003) which remained in the same village. 46 households do not have any new household units which remained in the same village but have at least one new household unit which emigrated to a nearby village. Remaining 51 households emigrated in the most restricted definition, that is, do not have any new household units which remained in the same village or emigrated to a nearby village.

We exclude households in the most urbanized four clusters since the model does not have human capital accumulation and occupational choice and poverty dynamics in urban area is very different from the one in the model and rural area. The ratio of employment income compared to agricultural income increased a lot in these four most urbanized clusters from 94 to 03. Although one fourth of households in KHDS wave 1 live in urban zone as mentioned above, we include households in urban zone except households in the most urbanized four clusters since urban zone except the most urbanized four clusters seems to be as agriculture-oriented as other zones in 91-94[8]. We drop 55, 51, and 41 households in these four clusters in 91, 92, and 04, respectively.

In order to focus on agricultural households, we drop households whose non-agricultural income or transfer income is larger than agricultural income. We also drop households which have outliers in variables used in our analysis. See Appendixes A.1.1, A.1.2, and A.1.3 for the details on how we drop samples.

4.2.1 only one continuing households among some split households

We exclude households which split from the original household between 1992 and 2003 and which does not seem to be continuing household from 1992. More particularly, we exclude the following households. If there is a main household where household head is

[7]Figure 1 of Beegle et al. (2006a) says that there are 912 original households although we find 919 households. Out of them, 17 households deceases, 63 households untraced, and 832 households are reinterviewed but we find 830 reinterviewed households.

[8]de Weerdt (2006) also excludes four urban clusters from his analysis. Since he did not mention what clusters they are, we could not confirm his four clusters are the same as our four clusters.

the same over 1992 and 2003 and there is another household which was split from the main household between 1992 and 2003, for example, a son's new household, we exclude the split household and focus on the main household. If a household head passed away between 1992 and 2003 and there are two households in 2003, for example, older brother's new household and younger brother's new household, we choose only one household as the continuing household and exclude the other household from our analysis. See Appendix A.1.4 for the detail on how to choose a continuing household.

The reason why we do so is two-fold. First, we do not have data on how a household divides its asset when one of household members leave the household and start his/her own new household. Second, even if we did have the data, we would need more complicated model to accommodate household division within the model. For example, if there are two sons, we need to model the probability of their new households and altruistic parameters on utilities of new households in the father's household utility function. Instead, we are assuming that each household has utility value only on the original household. Although the household expects household member's leave and division of asset as asset shock ϵ_{kjt}, it does not care how much utility the left member would obtain from divided assets[9].

We started with more simplified model by focusing on households whose heads have not been changed from 1991 to 2003 but this choice limited the generality of our analysis. First, most of households in wave 1 are severely affected by HIV as mentioned above, but we analyze only households whose heads have not passed away. Second, although death of household members are included as ϵ_{knt} in the model, we exclude the death of household head from our analysis. Thus, we decided to included households with change of head in our analysis.

[9] Aiyagari, Greenwood and Seshadri (2002) show a model where parent's utility function has altruistic terms for each children's welfare and parents invest in children's human capital based on such a utility function.

Table 1: Household split and attrition

													total
1991	from 1991 889												899
1992	same 774			new 55			d 60			from 1992 30			919
2003 based on 1992	same	new	d	same	new	d	same	new	d	same	new	d	
	465	254	55	27	25	3	21	11	28	16	12	2	919
identified	465	208		27	15		21	9		16	11		772
not identified	0	46		0	10		0	2		0	1		59
based on 2003	1647	764		92	71		44	21		58	43		2740
the data	276	99	22	15	1		6	0		8	4		431
use?	Y	Y	N	Y	Y		N			N	N		391

"based on 1992" means based on household unit (ID) in 1992, that is, we aggregate households in 2003 over the same original household in 1992.
"same" and "new" represent same head and new head, respectively.
"d" represents disappear.
"identified" and "not identified" shows whether one household is identified as the continuing household among households from the same original household or not.
"based on 2003" means based on household unit (ID) in 2003 and it show how many household splits happen between 1992 and 2003. For example, the second column shows that there are 465 households with the same head over 1991 and 2003 based on household unit in 1992 and those households split and the total number of household increased from 466 in 1992 to 1,647 in 2003.
"the data" is the constructed data for our analysis.
In "use?" row, each cell has "Y" if we use households in that category in our analysis and has "N" otherwise. We do not use households which do not have all 3 time period observations and the total number of households we analyze is 391.
Note that the total number of household in "based on 2003" row is 2,740 although in data there are 2,774 households in 2003. Thus, 34 households are missing in the table, mainly due to missing data on which member is household head. Although total number of households in 1992 is 919 in this table, Beegle et al. (2006a) p. 27 says that it is 912. See also Table VI.12 on page 61 of World Bank (2004) for the detail.

4.3 focus and limitations after choosing subsample of households

We do not include marriage, leaving parent's household and having new own household, and making children in choice set and we treat them as exogenous random events. We estimate these events within state transition function. Rosenzweig and Wolpin (1993) and Fafchamps and Pender (1997) do not include number of household members in their model at all. Thus, this paper extends their models in that sense. Some people might think that this simplification or strong assumptions are crucial disadvantage of the method. We think that this paper's contribution to the literature is still large enough even this limitation since benefit from showing and quantifying the mechanism of poverty dynamics or trap with explicit structural model outweigh this limitation[10]. It is possible, these dynamic decision is more important than investment in land and livestock. Also, investment in land and livestock may be closely related to decision of leaving parent's household[11]. Note that under our current specification below, ϵ_{klt}, ϵ_{kct}, and ϵ_{knt} are independent from each other although we could expect that a household transfers land to a male member when he leaves the household and starts his own household.

Household in the data do not use tractors and adopt particular new agricultural technology. de Weerdt (2006) mentions the change in crop choice over time from traditional to new more profitable crop, particularly from bananas and coffee (in North) and maize, sorghum and tobacco (in South) to cabbages, green peppers, tomatoes, pineapples, vanilla, fishing, and gold mining. However, he did not provide data supporting this statement. We checked the data but at this moment we have not found the change in crop he mentions.

We do not include accumulation of quality of human capital such as schooling in the model. de Janvry, Finan and Sadoulet (2005) treat schooling as a prerequisite to emigrate from rural to urban and obtain employed jobs in Mexico. Since we exclude households who emigrated and who live in urbanized area from our data set, we become less reluctant to exclude accumulation of human capital from the model. However, Foster and Rosenzweig (2002) show that human capital is important even in regions based on agriculture when there is rapid technological progress in agriculture. As we mentioned above, we do not find obvious changes in agricultural technology and crop choices in the data.

We do not include heterogeneity among regions in analysis although there is the following heterogeneity. Tree crop zone is in the northern part of Kagera and has high rainfall. Its main crop are bananas, coffee and tea. Annual crop zone in the southern part of Kagera and has lower rainfall. Cattle-owning households are not located in a particular zone.

4.3.1 Are land and livestock two main assets as productive assets and saving?

Our model is based on the assumption that land and livestock are two main assets not only as productive assets (sources of income generation) but also saving (tool for consumption smoothing) and play main roles in poverty dynamics. We discuss about the relevance of this assumption in the remaining parts of this section.

[10] This is a tautology.

[11] We thought we saw a paper which finds an empirical results that parents accumulate land with expectation of that their son's leave from their household. We checked Fafchamps and Quisumbing (2006) again but we did not find such a paper. Kochar (2004) finds that a household with less healthy son accumulates less productive asset compared to a household with more healthy son.

Asset structure in 91 and 92 is as follows: The value of land consists 42-59% of the value to total assets. The value of dwellings occupied by the owner household itself consists 18-30%. Other categories of assets are farm equipment, livestock, business asset, other dwellings, durable goods, farm inventory, business inventory, saving, loan, and debt. The value of each of them consists 0-6% except saving for the smallest asset quintile (9-10%) and other dwellings for the largest asset quintile (8-9%). At wave 1,117 out of 912 households own cattle and the value of livestock consists of 14-30% for the smallest four asset quintiles of cattle-owning households but only 9% for the largest quintile. At wave 2,117 out of 874 households own cattle and the value consists of 15-27% for the smallest four quintiles but only 6% for the largest quintile.

Land is the main productive asset and should be included in production function. However, whether land should be treated as endogenous variable is ambiguous. First, selling land is a very minor way for consumption smoothing as mentioned below. Second, investment and dis-investment do not occur often[12].

We thought cattle is the second most important asset for poverty dynamics in Kagera before we check the data. There are some reasons why we are afraid our first thought is not right. First, only 13-14% of households own cattle in 91 and 92. Second, plowing land by cattle does not seem common at all in Kagera. Third, selling livestock is not a major way for smoothing consumption as mentioned below. Fourth, cattle-owning households are more likely to be richer than non-cattle-owning households. Fifth, smaller livestocks such as chicken, sheep and goat might be more useful as saving asset for consumption smoothing. Because of these reasons, we decided to focus on total livestock instead of cattle.

KHDS in 03 asked households (1) whether each of the past ten years was very a bad year or not, (2) if so, why it was, and (3) if so, how did they cope with it. As the answer to (2) for year 2003, 25% of 376 individual singled out death of family member, 22% did poor harvest due to weather and 20% did serious illness. Our model includes household member's death as negative value of ϵ_{knt}. However, we do not include health in heterogeneity in k_{nt} although we could expect that bad health decrease production but also increase expenditure for medical care. Note that we allow ϵ_{knt} affect only $k_{n,t+1}$ although a household face the cost of funeral and has to transfer assets to other households as inheritance.

As the answer to (3), each individual could answer at most two and there are 525 answers for 2003 from 376 individuals. The content and percentage of each answer is as follows: rely on support from family and friends (30%), reduce consumption (19%), take casual employment (14%), introduce other crops (7%), sell livestock (6%), sell other assets (6%), start other business (5%), start selling processes food (3%), and sell land (2%). Based on these answers, including transfer in the model is one of potential extensions. Our model assumes that dis-saving assets is the only instrument for consumption smoothing but it is not true in the data. Labor/activity responses to negative income shock are more

[12]At wave 1, 3.3% of households (29 out of 888) bought land in the past 12 months. At wave 2-4, 1.1-2.2% bought land in the past 6 months. Inheritance is more often. At wave 1, 5.9% of households (52 out of 888) inherited land in the past 12 months. At wave 2-4, 2.6-2.8% inherited land in the past 6 months. We do not have data on land sold in wave 1. At wave 2-4, 0.7-1.1% and 0.5-1.1% of households sold and disinherited land in the past 6 months, respectively.

common than dis-saving assets. We are afraid we cannot modify the model for relaxing this limitation and we may remain it as one of our future research.

5 Estimation

We will fit the model to the data in the following two steps. First, we estimate agricultural production with unobserved productivity and asset transition functions separately and directly from the data. Second, we estimate remaining parameters (of utility and investment cost) based on the first-step estimates. In the second step estimation, there are inner loop and outer loop. In the inner loop we compute optimal investment decision given unknown parameters. On the other hand, in the outer loop we search parameter values with which computed investments are the closest to observed investment in the data.

5.1 First step estimation

5.1.1 Agricultural production function with panel data methods

Agricultural production function for household j at time t is $y_{ajt} = f(\alpha_j, k_{jt}, \epsilon_{yajt}; \theta_{ya})$ where α_j is unobserved time-invariant productivity, $k_{jt} = (k_{ljt}, k_{cjt}, k_{njt})$ and θ_{ya} is parameter vector. We include household time-variant term to control unobserved household characteristics which affect productivity and obtain better agricultural shock ϵ_{yat}. Otherwise, ϵ_{yat} would be contaminated by unobserved household characteristics which affect productivity. Barrett et al. (2008) show that households with different abilities may invest in productive asset very differently under credit constraints and non-convex production technology and thus we treat α_j as one of state variables.

We specify the functional form as follows:

$$\ln y_{ajt} = \alpha_j + \theta_{ykl} \ln(k_{ljt} + 1) + \theta_{ykc} \ln(k_{cjt} + 1) + \theta_{ykn} \ln(k_{njt}) + \epsilon_{yajt}.$$

We can estimate $\theta_{ya} = (\theta_{ykl}, \theta_{ykc}, \theta_{ykn})$ by panel data methods and denote it by $\hat{\theta}_{ya}$. Estimate of α_j is defined as follows: $\hat{\alpha}_j = \frac{1}{3}\sum_t \ln y_{ajt} - \hat{\theta}_{ya}\frac{1}{3}\sum_t \tilde{k}'_{jt}$ where $\tilde{k}_{jt} = (\ln(k_{ljt} + 1), \ln(k_{cjt} + 1), \ln(k_{njt}))$. Agricultural production shock is estimated as the residual: $\hat{\epsilon}_{yajt} = \ln y_{ajt} - \hat{\alpha}_j - \hat{\theta}_{ya}\tilde{k}'_{jt}$.

Table 2 shows the estimates. Figures 1 and 2 show the distributions of estimated household productivity $\hat{\alpha}_j$ and agricultural production shock $\hat{\epsilon}_{yajt}$, respectively.

We use this $\hat{\alpha}_j$ as one of state variables in order to control unobserved heterogeneity among households. We use the distribution of $\hat{\alpha}_j$ when we discretize α_j for computation. We use $\hat{\epsilon}_{yajt}$ too as one of state variables since each household knows the value of ϵ_{yajt} before it decides investments in the model. We use the distribution of $\hat{\epsilon}_{yajt}$ when we discretize ϵ_{yajt} and compute expected value of the value function in the next period.

Table 2: Agricultural production function

	estimate	s.e.
θ_{ykl}	0.2745	0.0459
θ_{ykc}	0.0128	0.0056
θ_{ykn}	0.5638	0.0555

The number of observations is 1,173 (= 391 households $\times$ 3 years).
s.e. (standard errors) are based on White's heteroskedacity-robust formula.
Mean of α_j $(= \mu_\alpha = (\sum \alpha_j)/391)$ is 10.09.
Variance of α_j $(= \sigma^2_\alpha = (\sum(\alpha_j - \mu_\alpha)^2)/391)$ is 0.22.
Variance of ϵ_{yajt} $(= \sigma^2_{\epsilon_{ya}} = (\sum \epsilon^2_{yajt})/(391 \times 3))$ is 0.26.

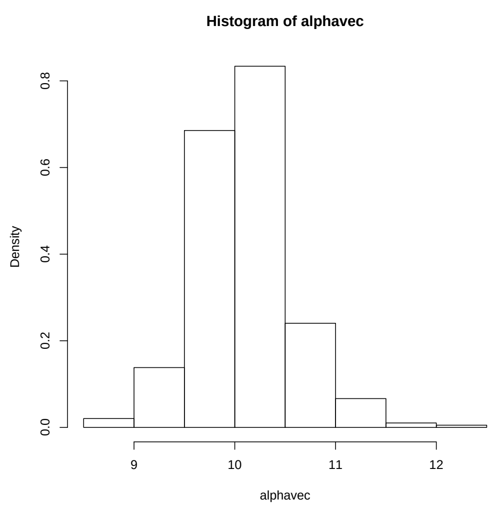

Figure 1: Distribution of α_j

The number of observations ($\hat{\alpha_j}$) is 391.
Mean of $\hat{\alpha}_j$ is 10.09
Minimum, 1st, 2nd, 3rd quantiles, and maximum of α_j are 8.62, 9.80, 10.07, 10.37, and 12.07, respectively.
Variance of α_j $(= \sigma^2_\alpha = (\sum(\alpha_j - \mu_\alpha)^2)/391)$ is 0.22.

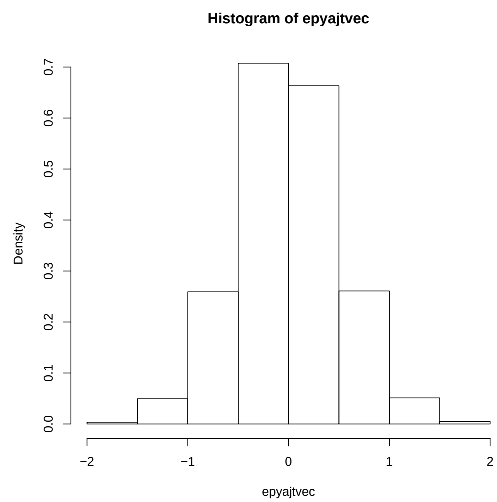

Figure 2: Distribution of ϵ_{yajt}

Mean of $\hat{\epsilon}_{yajt}$ is 0.00.
The number of observations ($\hat{\epsilon}_{yajt}$) is 1,173 (= 391 households $\times$ 3 years).
Minimum, 1st, 2nd, 3rd quantiles, and maximum of ϵ_{yajt} are -1.75, -0.33, -0.01, 0.35, and 1.72, respectively.
Variance of ϵ_{yajt} $(= \sigma^2_{\epsilon_{ya}} = (\sum \epsilon^2_{yajt})/(391 \times 3))$ is 0.26.

5.1.2 discussion on specification and estimation of production function

We estimate production function by utilizing panel data methods in order to obtain unobserved productivity and agricultural income shock as residual term of production function. The limitations of this estimation are as follows. First, we assume that productivity is time-invariant and thus no productivity growth over a decade. Second, we have only 3 observations over time and estimate of each household's productivity is not precise. Third, we assume the coefficients of assets are time-invariant. Fourth, we have only three explanatory variables and productivity α_j and shock ϵ_{yajt} accommodate all other hegerogeneities[13].

Other ways of specifying and estimating production function are categorized as follows: (1) Instrument variable (IV) method, (2) Olley and Pakes (1996), (3) stochastic frontier analysis (Kumbhakar and Lovell (2000)), (4) estimating it in the second step below, and (5) threshold estimation (Hansen (1999)).

Candidates of instruments for (1) IV method are input prices and lagged values of input use but we need to feasibility of this instruments and the method for our data-set. Blundell and Bond (2000) provides more sophisticated extensions of basic IV method. The concern is that if we use one time period lagged values of input use, we can use only data in 1991 and 1992 and not in 2003. Or we may use variables in 1992 as instruments for 2003 variables but remaining concern is how weak this instruments are.

(2) Olley and Pakes (1996) and Levinsohn and Petrin (2003) can be applied to our problem. Since we do not have variable input such as labor in firm, we can skip the first stage of their estimation. The concern is that we may use only data in 1991 and 1992 and not in 2003 since their methods may need panel data of consecutive time periods. Or we may use 1992 and 2003 too, since what we need to satisfy is that productivity follows first-order Markov process.

(4) If we estimate production function in the second step below in stead of estimating it in the first step, we control endogeneity of observed asset level in 1992 and 2003 although we do not control endogeneity of observed asset level in 1991, the initial period of our observations. However, computing time would increase and we are not less sure about whether identification of production is due to observed input and output or observed investment and asset accumulation.

(5) Threshold estimation (Hansen (1999)) is not only an alternative way of estimation but it allows us to estimate non-convex production more generally and this characteristic is important since we are interested in the possibility of poverty traps. Note that in the previous subsection, we specify production by traditional concave production function and non-convexity of production is only from lumpiness of investment. In the literature of poverty traps, some previous papers shows that poor households are trapped in poverty since they do not (cannot) choose a high-risk high-return technology or high-return technology with large fixed costs although rich households do. To accommodate these possi-

[13] If we added agronomic zone dummies and year dummies, they have statistically significant coefficients. Both year 1992 dummy and 2003 dummy have negative coefficients and the coefficient for 2003 dummy is smaller than the coefficient for 1992 dummy. It is difficult to know whether this result from (1) realization of shock, (2) declining trend in agriculture, or (3) our deflater is too large.

bilities, we can use threshold estimation[14]. We tried threshold estimation with the same set of households as in the previous subsection under different specifications[15] but we did not find statistically significant threshold. However, when we use only the subset of the households without change of household head, we found statistically significant threshold in livestock[16].

5.1.3 Asset transition probability function

Here, we estimate transition probability functions of land k_{ljt}, livestock k_{cjt}, and number of household members k_{njt} (equations (2), (3), and (4) above).

We assume that the probability density function of ϵ_{kljt} is a function of ϵ_{kljt} and k_{ljt}. We estimate the function directly from the data as follows. First, we discretize ϵ_{kljt} and k_{ljt}. Second, for each discretize value of k_{ljt}, we construct histogram of ϵ_{kljt} and treat the

---

[14]For example, we can specify production as follows:

$$\ln y_{ajt} = \begin{cases} \alpha_j + \theta_{yklL} \ln(k_{ljt}+1) + \theta_{ykcL} \ln(k_{cjt}+1) + \theta_{yknL} \ln(k_{njt}) + \theta_{yx} x'_{yjt} + \epsilon_{yajt} \\ \quad \text{if } \ln(k_{cjt}+1) > \gamma \\ \alpha_j + \theta_{yklS} \ln(k_{ljt}+1) + \theta_{ykcS} \ln(k_{cjt}+1) + \theta_{yknS} \ln(k_{njt}) + \theta_{yx} x'_{yjt} + \epsilon_{yajt} \\ \quad \text{otherwise} \end{cases}$$

where γ is threshold in livestock and subscripts L and S represent large and small amount of livestock, respectively.

[15]Different specifications are due to a mix of the following specification: (1) threshold variable can be land, livestock, or the number of household members, (2) allow which coefficients to be different when the threshold variable exceeds the threshold, and (3) whether add year dummies and logarithm of household head's age as explanatory variables.

[16]The results are under the following two specifications: Under the first specification, we allowed all coefficients of land, livestock, and the number of household members to be different when the threshold variable exceeds the threshold. Under the second specification, we allowed the fist two coefficients to be different. We added year dummies and logarithm of household head's age as explanatory variables under both specifications.

The result implies that top 11.7-13.9% livestock-holding households are more productive in land but less productive in livestock than other households. Note that agricultural income does not include revenue from trade and own-consumption of livestock itself since we treat trade and own-consumption of livestock itself as investment and disinvestment.

Although we have statistically significant results, the estimations are reduced form and we do not know why we have these results. One possible explanation is that households with large amount of livestock can insure themselves against agricultural production shock and thus can implement high-risk but high-return agricultural production. Another possible explanation is that households with large amount of livestock can finance agricultural cost over time and thus can implement agricultural production which needs large cost in particular time in production process such as fertilizer or labor for harvesting but brings higher returns. We have not investigate relevancy of these potential explanations by checking descriptive statistics of the data.

The non-convexity of agricultural production in livestock may generates poverty trap and threshold in the space of productivity (ability) and asset (livestock) as Barrett et al. (2008) show. They also show that there is large return to social protection policy in which a government or an agency provides transfer or insurance when households are hit by negative shock and knocked down below the threshold.

Note that even if we did not allow the possibility of thresholds in production or we did not find the thresholds in production, it would be still possible that there exists the threshold of poverty trap in the space of ability and asset. It is because lumpiness of investment in land or livestock generates production function which is a step function in land or livestock and this is a non-convexity of agricultural production.

computed histograms as the probability density function of ϵ_{kljt}. Figures 3 and 4 show the estimates.

We assume that the probability density function of ϵ_{kcjt} is a function of ϵ_{kcjt} and k_{cjt}. We estimate the function directly from the data in the same way as we do for ϵ_{kljt} above. Figure 5 shows the estimates.

We assume that the probability density function of ϵ_{knjt} is a function of ϵ_{knjt} and k_{njt}. We estimate the function directly from the data in the same way as we do for ϵ_{kljt} and ϵ_{kljt} above. Figures 6 and 7 show the estimates.

In the data, married sons and daughters are likely to get out out of their parents' household as Tables 3 and 4 show. A question is whether sons and daughters bring parents' assets with them when they get out of their parents' households. Based on simple regressions and figures for transition of land and livestock of the original households, household split decreases land but livestock of the original households. This result implies that there is correlation between ϵ_{knjt} and ϵ_{kljt} and thus we need to include this correlation when estimating asset transition probability functions.

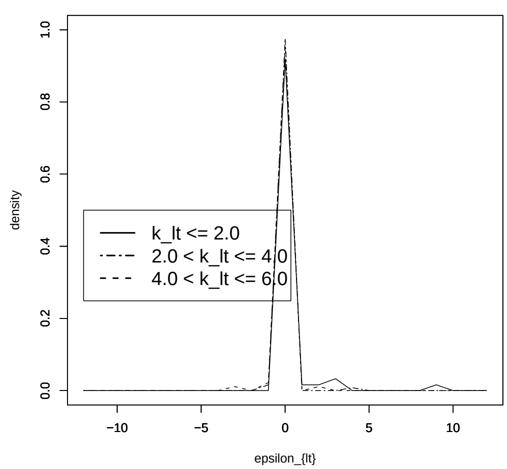

Figure 3: Distribution of ϵ_{lt} given k_{lt} at $t = 2$, $k_{lt} \leq 6.0$

Disretization is very coarse under the current setting: The boundaries for disretization of k_{lt} are 2.0, 4.0, $\cdots$, 10.0. The boundaries for disretization of ϵ_{klt} are -11.5, -10.5, $\cdots$, and 11.5. The number of observations is 391 (= 391 households $\times$ 1 year).

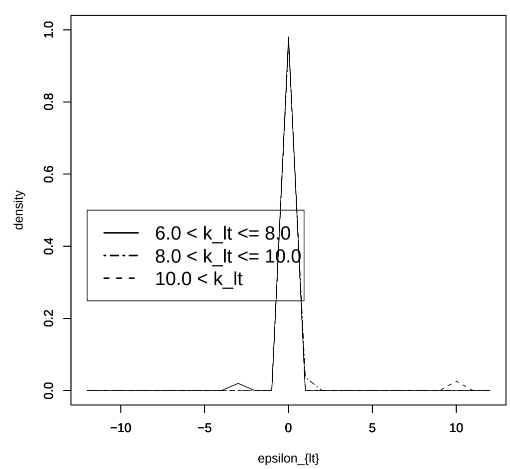

Figure 4: Distribution of ϵ_{lt} given k_{lt} at $t = 2$, $6.0 < k_{lt}$

Disretization is very coarse under the current setting: The boundaries for disretization of k_{lt} are 2.0, 4.0, $\cdots$, 10.0. The boundaries for disretization of ϵ_{klt} are -11.5, -10.5, $\cdots$, and 11.5. The number of observations is 391 (= 391 households $\times$ 1 year).

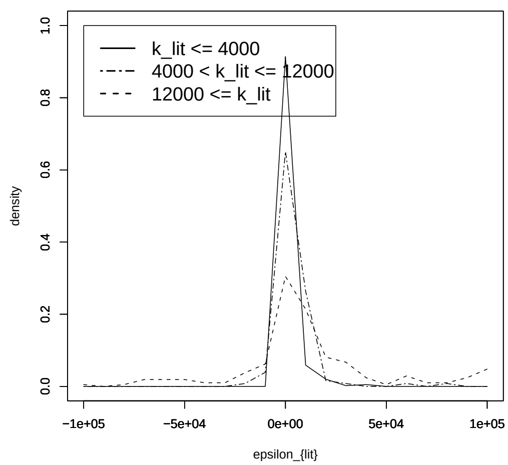

Figure 5: Distribution of ϵ_{ct} given k_{ct} at $t = 1$ and $t = 2$

Disretization is very coarse under the current setting: The boundaries for disretization of k_{cjt} are 4,000 and 12,000. The boundaries for disretization of ϵ_{kcjt} are -95,000, -85,000, $\cdots$, 85,000, and 95,000. The number of observations is 782 (= 391 households $\times$ 2 years).

Table 3: son's leave

	married in 2003	not married in 2003	total
leave before 2003	138	66	204
stay in 2003	23	116	139
total	161	182	343

Males whose fathers have been household heads since 1991 and who were not married in 1991 and whose ages are between 18 and 30 in 2003.

Table 4: daughter's leave

	married in 2003	not married in 2003	total
leave before 2003	227	41	268
stay in 2003	8	56	64
total	235	97	332

Females whose fathers have been household heads since 1991 and who were not married in 1991 and whose ages are between 18 and 30 in 2003.

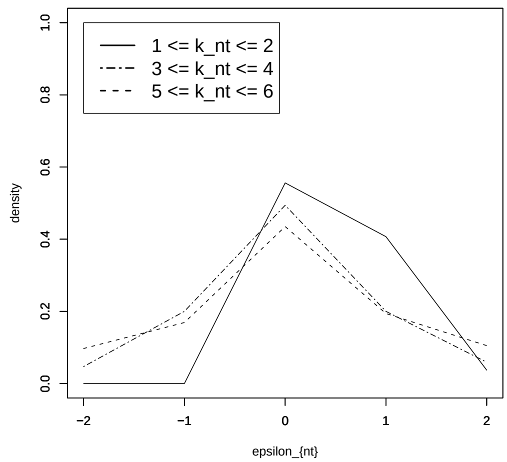

Figure 6: Distribution of ϵ_{nt} given k_{nt} at $t = 1$, $1 \leq k_{nt} \leq 6$

Disretization is very coarse under the current setting: The boundaries for disretization of k_{njt} are 2.5, 4.5, $\cdots$, 10.5. The boundaries for disretization of ϵ_{knjt} are -1.5, -0.5, 0.5, and 1.5. The number of observations is 391 (= 391 households $\times$ 1 year).

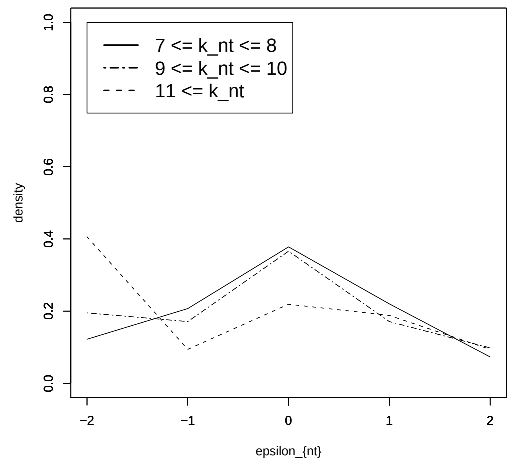

Figure 7: Distribution of ϵ_{nt} given k_{nt} at $t = 1$, $7 \leq k_{nt}$

Disretization is very coarse under the current setting: The boundaries for disretization of k_{njt} are 2.5, 4.5, $\cdots$, 10.5. The boundaries for disretization of ϵ_{knjt} are -1.5, -0.5, 0.5, and 1.5. The number of observations is 391 (= 391 households $\times$ 1 year).

5.2 Second step estimation

5.2.1 Utility function

We specify the utility function as follows

$$u(c_{jt}) = \sum_{m=1}^{k_{njt}} \tilde{u}(c_{jmt}) = \sum_{m=1}^{k_{njt}} \frac{c_{jm}^{1-\theta_u} - 1}{1 - \theta_u}$$

where $\theta_u > 0$, $c_{jmt} = c_{jt}/k_{njt} \, \forall m$, c_{jmt} is consumption of member m, c_{jt} is household total consumption, and k_{njt} is number of household members at t. Note that we assume that household allocates total consumption to each member equally and we do not use formula for calculating child's nutrition need compared to adult's one.

5.2.2 Investment cost function

Land investment cost function $e_l(i_{ljt}, p_{ilt}, \epsilon_{iljt})$ is specified as

$$e_l(i_{ljt}, p_{ilt}, \epsilon_{iljt}) = p_{ilt} i_{ljt} + \epsilon_{iljt}$$
$$\text{where } \epsilon_{ilt} \sim \text{Uniform}[\underline{\epsilon}_{il}, \bar{\epsilon}_{il}].$$

Households may not buy or sell land unless there are neighbor households who would like to sell or buy the land. ϵ_{iljt} captures this stochastic factor, which is unobservable for us as econometrician. The parameter vector of land investment cost function is $\theta_{il} = (\underline{\epsilon}_{il}, \bar{\epsilon}_{il})$. We choose relevant value of p_{ilt} from the data and fix it instead of treating is unknown and estimating it since we may not be able to identify p_{ilt} separately from $(\underline{\epsilon}_{il}, \bar{\epsilon}_{il})$.

5.2.3 Compute optimal investment (inner loop)

The Bellman equation of the household dynamic problem above is as follows:

$$
\begin{aligned}
& V(\alpha_j, k_{j\tau}, \epsilon_{yaj\tau}, y_{naj\tau}, p_{il\tau}, \epsilon_{ilj\tau}) \\
& = \max_{i_{j\tau}} \{u(c_{j\tau}) + \beta \mathrm{E}_\tau \left[V(\alpha_j, k_{j,\tau+1}, \epsilon_{yaj,\tau+1}, y_{naj,\tau+1}, p_{il,\tau+1}, \epsilon_{ilj,\tau+1}) | i_{lj\tau}, i_{cj\tau} \right] \} \\
& \text{ s. t. } c_{j\tau} + e_l(i_{lj\tau}, p_{ilj\tau}, \epsilon_{ilj\tau}) + i_{cj\tau} \leq f(\alpha_j, k_{j\tau}, \epsilon_{yaj\tau}) + y_{naj\tau} \\
& \qquad k_{lj,\tau+1} = k_{lj\tau} + i_{lj\tau} + \epsilon_{klj\tau} \\
& \qquad k_{cj,\tau+1} = k_{cj\tau} + i_{cj\tau} + \epsilon_{kcj\tau} \\
& \qquad k_{nj,\tau+1} = k_{nj\tau} + \epsilon_{knj\tau} \\
& \qquad y_{naj,\tau+1} = y_{naj\tau}
\end{aligned}
$$

We can compute optimal investment based on the optimization problem above given estimated production and asset transition functions and unknown parameters of utility function θ_u, land investment cost function $\theta_{il} = (\underline{\epsilon}_{il}, \bar{\epsilon}_{il})$, and time discount factor β. We use value function iteration method (See Appendix B for more details.).

5.2.4 check feasibility

The purpose of this subsection is to check whether we can actually compute the solution of the problem and how long it will take to compute it before we go through time-consuming estimation. In this subsection,

- We fix parameters for utility function as $\theta_u = 1.5$ and $\beta = 0.95$,
- fix the price of land investment as $p_{ilt} = 80{,}000$,
- assume that unobserved land investment cost ϵ_{il} does not exist. By the assumption, the land investment cost function becomes $e_l = p_{ilt} i_{lt}$.
- We discretize variables very coarsely, especially, $i_{lt} = \{-1.0, 0.0, 1.0\}$ and $i_{ct} = \{-8{,}000, 0, 8{,}000\}$. See Appendix B.3 for discretization of other variables. The total number of possible states is 2,592.

The number of value function iterations is 114. Computing time is 31 minutes. Table 5 shows optimal investments (i_{lt},i_{ct}) given agricultural production shock ϵ_{yat}.

5.2.5 Search unknown parameter values (outer loop)

We need to search the values of following unknown parameters: θ_u and time discount factor β in utility function and $\theta_{il} = (\underline{\epsilon}_{il}, \bar{\epsilon}_{il})$ for land investment cost function.

We use the methods of simulated moments (MSM). Moment conditions are simply $\mathrm{E}[k_j - \tilde{k}_j] = 0$ and $\mathrm{E}[(i_j|k_j) - (\tilde{i}_j|k_j)] = 0$ where k_j and i_j are vector of k_{jt} and i_{jt},

Table 5: Investments (i_l, i_c) given agricultural income shock ϵ_{ya}

ϵ_{yat}	i_{lt}	i_{ct}
-0.4	-1.0	8,000
0.0	-1.0	8,000
0.4	-1.0	8,000

Other state variables are fixed as $k_l = 3.0$, $k_c = 0.0$, $k_n = 5$, $y_{na} = 0.0$ and $\alpha = \mu_\alpha = 10.09$.

t = 91,92,03, respectively, $(i_j|k_j)$ is investment given asset level, $\tilde{k}_j$ is simulated values of k_j, and $(\tilde{i}_j|k_j)$ is computed values of $(i_j|k_j)$. We need to add more details based on Appendix E: Moment conditions of French (2003).

6 Results

6.1 Compare simulated results with data

We will compare original data with simulated data based on the estimated model in order to check how well the estimated model explain data. We have not done it yet.

6.2 Implement counter-factual policy simulations

We implement counter-factual policy simulations such as government transfer, insurance, etc. in order to quantify the magnitudes of potential determinant of poverty dynamics and study effective policy intervention for poverty reduction. We have not done it yet.

7 Conclusion

Appendixes

A Data

A.1 Construct data set

Wave 1 and wave 5 are annual surveys but wave 2, 3, and 4 are half-year surveys. In order to construct annual data, we combined wave 2 and 3 and threw away data of wave 4. The constructed data have 3 annual observations in 91, 92, and 03.

KHDS 91-94 added new households in the sample set from the middle of survey period (1991-1994) in order to replace drop-out households. If households received wave 1 questionnaires in the first two time intervals, called as "passages" in KHDS, we categorize them in the households from 1991 (889 households in the first row of Table 1). On the other hand, if households received wave 1 questionnaires in passage 3, we categorize them in the households from 1992 (30 households in (2,4) cell in Table 1).

We drop samples in each year as subsections A.1.1, A.1.2, and A.1.3 show. As mentioned in Section 4, we will focus on agricultural households by excluding households in the most urbanized for clusters and emigrated households. We also drop samples if household agricultural income is smaller than non-agricultural income or transfer income.

As mentioned in Section 4.2.1, we focus on only one continuing household among other households from the same original household. Appendix A.1.4 explains how we choose a continuing household. We choose it regardless of whether each household is dropped or not for focusing agricultural households.

After dropping samples in each year and identifying a continuing household, we combine them and construct panel data by excluding households if each of households does not have the identified continuing household or each of households is dropped in any year as outliers or non-agricultural households. Table 1 shows the number of households in the constructed data set ("the data" row).

A.1.1 1991

We drop observations in 1991 as follows.

- There are 855 observations with positive agricultural income.
- Drop 51 observations in 4 clusters in ward 12 since these clusters are much more urbanized than other clusters[17]
- Drop 2 observations with $k_{l,t+1} = 0$.

[17] The mean and median of the ratio of agricultural income to total income excluding transfers among households in this ward is 0.34 and 0.23 respectively. de Weerdt (2006) excludes 4 urban clusters from his analysis since those clusters are much more urban than other clusters. Since he does not mention what these clusters are, we do not know we drop the same four clusters but we guess so. We do not drop observations in other clusters in urban zone since the ratio is not so small in 1991 and 1992. However, we have not checked how much urbanization proceeded between 1992 and 2003. If other clusters in urban zone are much more urbanized than other clusters in other agronomic zones, we have to drop more observations.

- Drop 3 observation since they have much larger livestock shock ($\epsilon_{ct} > 500{,}000$) than other households.
- Drop 1 observation since it has very large numbers of household members ($k_{nt} = 27$).
- Drop 100 observations since their non-agricultural incomes are larger than agricultural income.
- Drop 3 observations since their agricultural incomes are very small ($y_{at} = 1{,}820, 2{,}300, 8{,}140$).
- Drop 1 observation since net transfer sent is larger than agricultural income.
- Drop 5 observations since net transfer received is larger than agricultural income.
- Drop 5 observations since sum of non-agricultural income and net transfer received is larger than agricultural income.
- The numbers of remaining observations is 684.

A.1.2 1992

We drop observations in 1992 as follows:

- There are 840 observations with positive agricultural income.
- Drop 55 observations in 4 clusters in ward 12 since these clusters are much more urbanized than other clusters.
- Drop 3 observations since they have negative value of total livestock in monetary value k_{ct}.
- Drop 2 observations since it sell much larger livestock than other household.
- Drop 1 observation since they have very large negative livestock shock ($\epsilon_{ct} < -1{,}170{,}000$).
- Drop 2 observation since it has very large positive livestock shock ($\epsilon_{ct} > 600{,}000$).
- Drop 2 observations since they have very large number of household members ($k_{nt} = 26, 28$).
- Drop 82 observations since their non-agricultural incomes are larger than agricultural income.
- Drop 2 observations since their agricultural incomes are very small ($y_{at} = 5{,}160, 8{,}415$).
- Drop 13 observations since net transfer received is larger than agricultural income.
- Drop 13 observations since sum of non-agricultural income and net transfer received is larger than agricultural income.
- The numbers of remaining observations is 665.

A.1.3 2003

We drop observations in 2003 as follows:

- There are 2,774 observations before dropping.
- Drop 1,482 observations since these households emigrated between 1994 and 2003 and KHDS ask only some parts of questionnaire to these households[18].
- Drop 41 observations since they have zero agricultural income.
- Drop 18 observations since they have negative value of agricultural income y_{at}.
- Drop 31 observations in 4 clusters in ward 12 since these clusters were much more urbanized than other clusters in 1991.
- Drop 1 observation with missing value of $k_{l,t+1}$.
- Drop 8 observations with $k_{l,t+1} = 0$.
- Drop 155 observations since their non-agricultural incomes are larger than agricultural income.
- Drop 5 observations since they have much smaller agricultural income $y_{at} < 10{,}000$ than other households.
- Drop 2 observations since agricultural income y_{at} are much larger than other households.
- Drop 4 observations since net transfer sent is larger than agricultural income.
- Drop 24 observations since net transfer received is larger than agricultural income.
- Drop 10 observations since sum of non-agricultural income and net transfer received is larger than agricultural income.
- The numbers of remaining observations is 993.

A.1.4 choosing a continuing household among households from the same original household

There are two main ways for choose main household among split households: (1) choose the household which has the largest number of original household members, or (2) choose the household where original head's spouse or son becomes head if household head changes. We checked data and it looks like these two choices give us similar results since there are obvious correlations between these two characteristics of households. We mixed these two choices as follows.

[18] 1,012 households are non-main households. We drop 454 households who emigrated to nearby villages. We drop 1 household who emigrated to elsewhere in Kagera. We drop 4 households who emigrated to elsewhere in Tanzania. We drop 11 households who emigrated to neighbouring country, which supposes to be categorized as non-main households. 1,482 = 1,012+454+1+4+11.

First, we make score of the relevancy as a candidate for continuing household as Table 6 shows. Second, if there is tie based on the score among households with score 5 or more from the same original household, we choose the household which has the largest number of original household members. Third, if there is no household with score 5 or more from the same original household, we choose the household which has the largest number of original household members. If there is tie based on the household which has the largest number of original household members, we choose the household with the highest score.

Table 1 shows the number of households which are identified and not identified household as a continuing household ("identified" row and "not identified" row).

Table 6: score of relevancy as a continuing household

score	current head	original head	spouse	son	daughter	N
11	original head		1			247
10	original head		0			298
9	spouse	1				1
8	spouse	0				110
7	son	1				2
6	son	0	1			5
5	son	0	0			405
4		1				21
3		0	1			36
2		0	0	1		86
1		0	0	0	1	519
0						1044

N represents the number of households. The second column "current head" shows who is the current head. The third to the last columns show the existence of each kind of original members. For example, a cell in the third column "original head" has 1 if the original head exists in a household and has 0 otherwise.

A.2 Construct variables

A.2.1 Land

Hectare of land in the beginning of period t is denoted by k_{lt} where subscript l is from the initial of land[19]. KHDS asked hectare of land at the time of survey and we treat it as $k_{lt'} = k_{lt} + i_{lt} + \epsilon_{klt}$ (hectare of land in the end of period t, denoted by t') for 1991, 1992, 2003.

KHDS asked each household how much it bought both in hectare and in monetary value for 1991 and 1992. However, KHDS asked how much a household sold only in monetary value and only for 1992. We constructed hectare of land sold by dividing monetary value of land sold $i_{lv,sell,t}$ by price of land per ha p_{kl}. Price of land per ha p_{kl} assumes to be equivalent to the median of the monetary value divided by ha of land owned and used in the end of period $(= k_{l,v,ou,t+1}/k_{l,ou,t+1})$[20]. Then, we construct hectare of land invested by subtracting land sold from land bought, that is, $i_{lt} = i_{l,buy,t} - i_{l,sell,t}$.

KHDS asked each household how much land it inherited both in hectare and in monetary value for 1991 and 1992. However, KHDS asked how much land a household disinherited only in monetary value and only for 1992. We construct hectare of land disinherited by dividing monetary value of land disinherited $\epsilon_{lv,dis,t}$ by price of land per ha p_{kl}. Price of land per ha p_{kl} assumes to be equivalent to the median of the monetary value divided by hectare of land owned and used in the end of period $(= k_{l,v,ou,t+1}/k_{l,ou,t+1}$, see footnote 20). Then, we construct hectare of land accumulation shock by subtracting land disinherited from land inherited, that is, $\epsilon_{lt} = \epsilon_{l,inherit,t} - \epsilon_{l,disinherit,t}$.

We obtained hectare of land in the beginning of the period (year 1992 only) by subtracting i_{lt} and ϵ_{lt} from $k_{lt'}$, that is, $k_{lt} = k_{lt'} - i_{lt} - \epsilon_{klt}$. Because of data limitation, we can construct i_{lt}, ϵ_{lt}, and k_{lt} only for 1992. We use these variables to estimate the distribution of land accumulation shock ϵ_{lt} and to estimate unknown parameters in the second step estimation as data on land investment decision. However, in order to estimate production function, we use hectare on land in the end of each period $k_{lt'}$ in order to increase number of observations although it is odd to assume that households can use land invested or inherited in the middle of each period for production.

A.2.2 Livestock

Monetary value of livestock in the beginning of period t is denoted by k_{ct} where subscript c is from cattle. KHDS asked the monetary value of each livestock at the time of survey and we treat the total value of livestock as $k_{ct} + i_{ct} + \epsilon_{kct}$ (the monetary value of livestock in

[19]We could divide land based on rent-in and rent-out as follows:

- k_{lout}: Own and use. Subscript ou represent "own use".
- k_{lrot}: Rent-out and own. Subscript ro represent "rent-out".
- k_{lrit}: Rent-in and not own. Subscript ri represent "rent-in".
- k_{loft}: Own and fallow. Subscript of represent "own and fallow".

However, we do not do so. The reason is to decrease the dimension of state variables and most of land is categorized in "own use".

[20] The medians of the monetary values divided by ha of land owned and used in the end of period $(= k_{l,v,ou,t+1}/k_{l,ou,t+1})$ in wave 2, 3, and 4 are 80,000, 86,666.7, and 96,428.6, respectively.

the end of period t) for 1991 and 1992. KHDS asked each household how much it bought, sold and ate and we construct investment i_{ct} based on them. Note that we treat own consumption of livestock as disinvestment or dis-saving instead of consumption or income. KHDS asked how many livestocks were (1) lost, stolen, disinherited, or died and (2) born, received as gift and we construct asset shock ϵ_{kct} based on these. Then we obtain k_{ct} the monetary value of livestock in the beginning of period t by subtracting i_{ct} and ϵ_{kct} from $k_{ct} + i_{ct} + \epsilon_{kct}$.

In 2003 KHDS did not ask households about i_{ct} and ϵ_{kct} in the same way as in 1991 and 1992 and data on i_{ct} and ϵ_{kct} in 2003 are much less complete than those in 1991 and 1992. Thus, we treat the total monetary value of livestock at the time of survey as k_{ct}.

We assume that households use k_{ct} for production at t and i_{ct} and ϵ_{kct} do not affect the production of production at t.

A.2.3 other variables

- Household size k_{nt} is just the total number of household members. We have not taken into accounts heterogeneity in gender and age.
- Agricultural income y_{at} includes own consumption of agricultural products but does not include imputed value of rent of house which a household own and use by itself. Own consumption of livestock is not included in agricultural income but included in (dis)investment i_{ct}. On the other hand, own consumption of animal products such as milk and egg is included in agricultural income.
- Non-agricultural income y_{nat} includes net transfer received m_t, which is summation of transfers among households and transfer from and to institutions such as religious group and funeral insurance group.

A.2.4 Inflation

We could not find the data on inflation in Kagera. We assume inflation rate is 13% and ratio of nominal price in 1992 and 2003 to that in 1991 are 1.13 and 4.33, respectively. Although we do not construct this inflation rate rigorously by weighting increase in price of each consumption good based on consumption amount of each good, the number matches price data in KHDS. We discount nominal price by this inflation rate in order to obtain real monetary values of variables.

A.3 Variables from other data

A.3.1 poverty line

World Bank has two kinds of poverty line based on annual expenditure for Tanzania. Relative poverty line is 46,173 TZS and and absolute poverty line is 31,000 TZS (World Bank, Tanzania Poverty Profile, p.16; JICA 1997 p.263). Note that both lines are lower than one dollar per day line (227 and 152 US dollar with exchange rate where one dollar is 203 TZS in 1993). The percentage of population under absolute and relative poverty line in Kagera in 1991 are 36.5% and 17% respectively (World Bank 1993 Tanzania Poverty

Profile; JICA 1997 p.266). Note that these percentage are much higher in rural area than urban area.

Beegle, de Weerdt and Dercon (2006b) use the basic needs poverty line of 109,663 TZS for 1991 and 2004 but did not mention how to obtain it.

At least on December 1996, Tanzania government does not have its own poverty line (JICA 1997 p. 262).

Poverty rate in North and East region of Tanzania (Kigoma, Kagera, Kilimanjaro and Arusha) is 40.2% in 1993. This number based on income and Cornell-ERB Survey (World Bank PHRD, 1993; World Bank, Agriculture in Tanzania Since 1986, June 2000, p.98; JICA, 2001, p.2-18).

A.3.2 other variables

One United States dollar (USD) is equivalent to 219.2 and 297.7 Tanzania shilling (TZS) in 1991 and 1992 respectively (International Finance Statistics (IFS) 1999; Japan International Cooperation Agency (JICA) 2001 p.2-5)

Per capita Gross National Products (GNP) of Tanzania in 1991 and 1992 are 41,998 TZS (191.6 USD) and 50,489 TZS (169.6 USD), respectively (International Finance Statistics (IFS) 1999; JICA 2001 p.2-5)

Calorie intakes per day in Tanzania in 1996 is 2,028 (3,350 in USA; FAO 1999; UNDP Human Development Report 1999; JICA 2001 p.2-46).

The ratio of Per capita food production in 1997 to one in 1989-1991 is 0.94, that is, per capita food production decreased (FAO 1999; UNDP Human Development Report 1999; JICA 2001 p.2-46).

In 1997, 10% of adults in Tanzania have HIV (JICA 2001, p.2-48).

B Computation

B.1 Value function iteration

Denote state variables $(\alpha_j, k_{jt}, \epsilon_{yajt}, y_{najt}, p_{ilt}, \epsilon_{iljt})$ by s_{jt}.

Drop subscript j for notational simplicity.

We compute the value function by the following iterations:

- Discretize s into $s_1, s_2, ..., s_n$.
- Define $V_0(s_q) = 0$ for all s_q and $\epsilon = 0.04$.
- $l = 0$.
  Repeat the following until $||V_{l+1}(s) - V_l(s)|| < \epsilon$ holds for every s [21].

[21] An alternative is as follows: Repeat the following until $||V_{l+1} - V_l|| < \epsilon$ holds.

For $q = 1, ..., n$, compute $i_q = (i_{lq}, i_{cq})$ which solves the following problem:

$$\begin{aligned} V_{l+1}(s_q) &= \max_{i_q}\{u(c_q) + \beta \mathrm{E}\left[V_l(s')\right]\} \\ \text{s. t. } & c_q + e(i_{lq}, p_{ilq}, \epsilon_{ilq}) + i_{cq} \leq f(\alpha, k_q, \epsilon_{yaq}) + y_{naq} \\ & k'_l = k_{lq} + i_{lq} + \epsilon_{klq} \\ & k'_c = k_{cq} + i_{cq} + \epsilon_{kcq} \\ & k'_n = k_{nq} + \epsilon_{knq} \end{aligned}$$

Go forward to next iteration $l + 1$.

- The value function V is defined by the final V_{l+1}.

The policy function is defined as follows:

$$\begin{aligned} & i(s_q) \equiv \mathrm{argmax}_{i_q}\{u(c_q) + \beta \mathrm{E}\left[V(s')\right]\} \\ & \text{s. t. } c_q + e(i_{lq}, p_{ilq}, \epsilon_{ilq}) + i_{cq} \leq f(\alpha, k_q, \epsilon_{yaq}) + y_{naq} \\ & \quad k'_l = k_{lq} + i_{lq} + \epsilon_{klq} \\ & \quad k'_c = k_{cq} + i_{cq} + \epsilon_{kcq} \\ & \quad k'_n = k_{nq} + \epsilon_{knq} \end{aligned}$$

B.2 uniqueness of value function

We need to show our computation of value function by value function iteration provides unique solution. We can follow the proof of Theorem 12.1.1 on page 402 in Judd (1998) or that of Theorem 9.6 on page 263 in Stokey and Lucas (1989). The former looks more general and we try to follow it. Define map T as follows:

$$\begin{aligned} & (TV)(s) \equiv \max_{i}\{u(c) + \beta \mathrm{E}\left[V_l(s')\right]\} \\ & \text{s. t. } c + e(i_l, p_{il}, \epsilon_{il}) + i_c \leq f(\alpha, k, \epsilon_{ya}) + y_{na} \\ & \quad k'_l = k_l + i_l + \epsilon_{kl} \\ & \quad k'_c = k_c + i_c + \epsilon_{kc} \\ & \quad k'_n = k_n + \epsilon_{kn} \end{aligned}$$

Note that T is a map from a functional space to the same functional space and we are considering the functional space for the value function.

We show that T is a contraction with modulus β and then use contraction mapping theorem.

First, we claim that T is monotone. Suppose $Y(s) \leq X(s)$ for all s.

$$\begin{aligned} (TY)(s) &= \max_{i}\left\{u(c) + \beta \mathrm{E}Y(s')\right\} \\ &= u(c^*) + \beta \mathrm{E}Y(s') \\ &\leq u(c^*) + \beta \mathrm{E}X(s') \quad (\text{since } Y(s') \leq X(s')) \\ &\leq \max_{i}\left\{c) + \beta \mathrm{E}X(s')\right\} \\ &= (TX)(s) \end{aligned}$$

Next, we claim that T satisfies the property "discounting".

$$\begin{aligned}(T(V+a))(s) &= \max_i \left\{u(c)+\beta\mathrm{E}[V(s')+a]\right\} \\ &= \max_i \left\{u(c)+\beta\mathrm{E}V(s')\right\}+\beta a \\ &= (TV)(s)+\beta a\end{aligned}$$

As we showed above, T satisfies Blackwell's sufficiency conditions[22], monotonicity and discounting, and thus T is a contraction with modulus β. Then, by Contraction Mapping Theorem[23] or Theorem 12.1.1 on page 402 in Judd (1998),

- T has exactly one fixed point V^* and
- for any V_0 and any n, $d(T^n V_0, V^*) \leq \beta^n d(V_0, V^*)$.

Thus, we can compute the solution by value function iteration mentioned above.

B.3 Discretization

State variables:
$k_{lt} = \{1.0, 2.0, 3.0, 4.0\}$
$k_{ct} = \{0, 8{,}000, 16{,}000, \cdots 40{,}000\}$
$k_{nt} = \{1, 2, \cdots 6\}$
$y_{nat} = \{0.0, 10000.0\}$
$\epsilon_{yat} = \{-0.4, 0.0, 0.4\}$
$\alpha = \{-9.6, 10.1, 10.6\}$
The total number of possible states is 2,592 $= 4 \times 6 \times 6 \times 2 \times 3 \times 3$.
Control variables:
$i_{lt} = \{-1.0, 0, 1.0\}$
$i_{ct} = \{-8{,}000, 0, 8{,}000\}$

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