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The Role of Credit and Deposits in the Dynamics of Technology Decisions and Poverty Traps

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The Role of Credit and Deposits in the Dynamics of Technology Decisions and Poverty Traps

Abstract

This paper investigates the farm-household decisions of adopting and abandoning higher-productivity technologies, under different scenarios of inclusion into the credit and deposit markets. The financial environment is further characterized by shallow financial markets, represented by a comparatively large wedge between high interest rates charged on loans and low interest rates paid on deposits and by relatively stringent borrowing limits. Via the numerical approximation of infinite horizon, dynamic, stochastic models, the analysis begins by solving the representative farmer's dynamic decision problem for three different scenarios of financial exclusion/inclusion in just loan or deposit markets. Then, by expanding the model to a whole economy of heterogeneous farmers, the effects of financial development are examined at the aggregate level. The results show that the scenarios of partial inclusion, either to deposits or to credit markets, bring notably greater benefits in terms of the sustained adoption of the advanced technology than the scenario of financial exclusion. Simulations using different borrowing limits show that, unless the credit limit is sufficiently nonrestrictive, the provision of deposit facilities is a superior policy to boost the rates of technology adoption and prevent its abandonment. In the case of credit, the steady-state adoption rates are insensitive to the interest rate levels. Thus, the simulations actually reflect cases of non-interest credit rationing. In contrast, when only deposit facilities are available, the adoption rate is higher and the abandonment rate is lower as the interest rates paid on financial savings increase.

1 Introduction

In developing countries, the adoption and retention of higher-productivity technologies may serve as a basis for increasing household-farm incomes and, thereby, accelerating a transition out of poverty. For most poor household-farms, however, the adoption of advanced technologies may be unaffordable or it may appear as highly risky. In particular, the required investment may be so large and lumpy or so risky that it is likely that poverty traps would emerge from the constraints to adoption. Furthermore, household-farms' exposure to increased downside income risk, followed by the adoption, may discourage the retention of the technology. Hence, despite the potentially large benefits that some innovations may promise, numerous complexities of technological choices have been extensively documented (Feder, Just, and Zilberman, 1985; Sunding and Zilberman, 2001; Doss, 2006; Suri, 2011).

This paper explores the particular influence of three broadly defined dimensions of financial development (financial inclusion, credit rationing, and financial deepening) in overcoming the poverty traps inherent in the adoption and retention of superior production technologies. The major objective is to explain the differential effects of access to credit and deposit facilities that allow financial savings on technology choices. Then we mainly focus on financial inclusion. Inclusion results from a reduction of obstacles to the use of these services, whether these obstacles are price or non-price barriers to access. It implies both access to -namely, the possibility to us- financial services and the actual use of those services. As a dimension of economic development, financial inclusion has often been overlooked, mostly because of major data gaps on who has access to which financial services and of a lack of systematic information on the barriers to broader access.

Throughout the paper we explore a scenario of full financial exclusion, and two of partial financial inclusion (one where farmers only have access to deposit facilities and another one in which they only have access to credit). Results from these base scenarios are then compared to a scenario of financial inclusion (where access to credit and deposit facilities is allowed). To better describe an environment where the financial markets are poorly developed, we set severe borrowing limits (credit rationing) in the scenarios where borrowing is allowed, and a wedge between the interest rates on loans and deposits (financial deepening). Each

scenario of financial inclusion considered is summarized in a representative farmer's decision problem, which is characterized by recursive Bellman equations. We begin by solving the representative farmer's problem. Then we expand the model to allow for a population of many farmers who behave as the representative agent, but who otherwise are heterogeneous with respect to wealth and technology state, as a result of having experienced distinct, idiosyncratic production shocks over time. With these models, we are able to examine the role of deposits and credit on technology decisions at the aggregate level.

The efficient provision of financial services -credit and deposit facilities- may play a determinant role in the process of adoption and retention of advanced technologies by poor household-farms. Credit-constrained household-farms cannot increase their command over resources beyond their current endowments and beyond their access to limited amounts of informal credit, even though the value of the marginal product of those resources would be higher than the repayment of principal and interest on institutional loans (Gonzalez-Vega, 1980; Braverman and Guash, 1986; Deaton, 1991). In particular, self-financing or access to just informal finance may not be sufficient to allow poor household-farms to adopt costly and risky advanced technologies, while several types of barriers may limit their access to institutional loans and thereby keep them credit-constrained.

Similar sources of market failure also constrain the demand and supply of deposits by financial intermediaries, particularly in the absence of an appropriate framework of prudential regulation (McKinnon, 1989; Chaves and Gonzalez-Vega, 1994, Bhattacharya, Boot and Thakor, 1998; Dewatripont and Tirole, 1999). As a consequence, poor household-farms without access to convenient, liquid, and safe deposit facilities may either keep some of their resources as idle and illiquid precautionary reserves (Gomez-Soto, 2007) or they may make production and technology choices that do not represent a socially optimum allocation of their resources (Jalan and Ravalion, 2001). Thus, limited access to deposit facilities and not just limited access to credit may inhibit the adoption of superior technologies.

A number of empirical studies have actually examined the incidence and importance of credit constraints in production decisions and levels (Rosenzweig and Wolpin, 1993; Morduch, 1995; Jacoby and Skoufias, 1998; Kochar, 1999; Armendariz and Morduch, 2005). Non-experimental studies have frequently reported large benefits of removing these credit

constraints (Bravo-Ureta and Pinheiro, 1993; Sherlund, Barrett and Adesina, 2002; Chavas, Petrie and Roth, 2005; McKenzie and Woodruff, 2006; Udry and Anagol, 2006; Alpizar, 2007). Widespread challenges -emerging from weak identification in some of those empirical studies- have led to the growing use of randomized controlled trials (Banerjee and Duflo, 2008; Duflo, Glennerster and Kremer, 2008), including a few experimental efforts to measure the impacts of greater access to institutional financial services (Banerjee and Duflo, 2010). Although a few of these randomized experiments have reported some mixed results regarding the impact on incomes of access to financial services (de Mel, McKenzie and Woodruff, 2008; Banerjee et al., 2009; de Mel, McKenzie and Woodruff, 2009; Karlan and Zinman, 2009), by recognizing some other welfare-improving impacts of financial inclusion, such as better opportunities for consumption smoothing and human capital investment (Lloyd-Ellis and Bernhardt, 2000; Aghion and Armendariz de Aghion, 2004; Ahlin and Jiang, 2008; Maldonado and Gonzalez-Vega, 2008), most of these authors have often acknowledged the value of interventions that would help remove existing credit constraints.

Although less frequently studied, savings constraints -resulting from the absence of deposit facilities- may also affect the efficiency of production (Von Pischke, Adams and Donald, 1983; Adams, Graham and Von Pischke, 1984; Robinson, 1998;Yaron, Benjamin and Charitonenko, 1998; Karlan et al., 2010; Brune et al., 2011; Dupas and Robinson, 2012). Deposit facilities allow household-farms both to overcome liquidity constraints (Parker, 2000; de Meza and Webb, 2003), by facilitating the accumulation of financial assets, as well as address the limitations -due to high costs and risks and a covariance with systemic shocks- of holding precautionary reserves in kind (Fafchamps, Udry and Czukas, 1998; Jalan and Ravallion 2001; Kazianga and Udry 2006; Gomez-Soto, 2007).

Building on reasonable assumptions about the welfare enhancing role of both types of financial services and based on the preponderant evidence from the theoretical and empirical literature, this research focuses on an assessment of the particular influence of credit and deposits on the adoption of those advanced technologies that require lumpy and/or risky investments, in an environment where the financial markets are poorly developed. Although -potentially- there are numerous sources of poverty traps, risk and lumpy investments embed traps that have a direct relationship with access to financial markets:

1. First, assume that a farm-household has access to both a low-return but low-risk production technology and to a higher-return but riskier technology. Due to the lack of financial mechanisms that would allow the farmer to cope with income shortfalls, the best choice is to remain caught in using the safer technology, despite its lower returns. In contrast, adoption of the high-return technology may place a farmer with a low level of wealth in such a highly vulnerable situation that farmers would not be willing to adopt. Thereby, the poor farm-household's expected returns would be permanently low.

2. A second type of trap may be caused by the lumpiness of the investment required to undertake the more profitable activity. Let us consider a farm-household that has the choice of two activities, ignoring for this case differences in risk. One of these activities yields higher returns, but it cannot be operated at a low scale. In other words, the agent must invest a relatively large amount to begin its operation. If the households have no means to accumulate this minimum amount or borrow for this, they would not be able to afford adoption.

Furthermore, assuming that the farm-household is able to accumulate sufficient wealth to afford the advanced technology and to manage the risk associated to it (by continuously reinvesting in the low-return technology or by using deposit facilities to accumulate wealth). In an environment with poorly functioning financial markets and in the absence of bequest motives, the farm-household may not be willing to adopt. Because of low returns on financial savings, accumulation may take a long time, so that the rewards in future consumption do not compensate current consumption sacrifices. Therefore, poor households are condemned to live in poverty conditions.

There have been several attempts to empirically explore the role of deposits and credit in the adoption of advanced technologies (although the majority only considers divisible technologies, which may not require large investments and therefore not necessarily capture a poverty trap). By using cross-sectional data to estimate the models, it has been argued that the provision of credit may encourage the adoption of divisible advanced technologies (Salasya, et al., 1998; Ouma et al., 2002; Croppenstedt, Demeke, and Meschi, 2003). While

such static studies may offer insights about the importance of some determinants of adoption, several methodological concerns may question, however, the validity of their suggestions. For instance, these authors usually fail to control for the farmers' heterogeneity, a critical issue that leads to biased estimates. If these results were taken seriously, they might lead to misleading policy interventions.

Possibly because of the difficulties to isolate the effect of the variable of interest with non-experimental approaches, controlled randomized experiments to study the influence of access to financial services on technology decisions have also been implemented (Duflo, Kremer, and Robinson, 2006; Gin and Yang, 2009; Karlan et al., 2010). A fundamental concern about these studies has been that they contain no information about the nature of the process of adoption (Cameron 1999; Moser and Barrett, 2003; Doss, 2006).

Taking into consideration the dynamics of adoption may be critical, in particular, when the researcher is interested in analyzing the distributional effects of new technologies (Doss, 2006), when farmers can gradually switch from traditional to modern technologies, as this involves a process of learning (Foster and Rosenzweig, 1995; Cameron, 1999; Moser and Barrett, 2003; Duflo, Kremer, and Robinson, 2008; Conley and Udry, 2010), as well as when the adoption requires a period of prior accumulation (Fafchamps and Pender, 1997; Dercon, 1998). Understanding the dynamics of the process then becomes utterly important in studies that attempt to analyze poverty traps since, by definition, they refer to a state of persistent poverty.

Due to the limitations of cross-sectional data, attempts to estimate richer reduced specifications by using longitudinal data have also been made (Moser and Barrett, 2003; Dercon and Christiaensen, 2011). However, given the strong endogeneity that exists between financial access and technology adoption -and given that the dependent variable is usually binary- the estimation of econometric specifications that control for household fixed effects and incorporate dynamic terms is poorly achieved. The difficulties to incorporate dynamic terms probably also explain why the study of the abandonment of superior technologies has been sluggish.

However, the story of the influence of financial development on poverty traps transcends just the ability of farm-households to adopt superior technologies and it should include their

ability to sustain such adoption. Understanding the role of financial mechanisms for the design of policies that facilitate the prevention of technology abandonment is, therefore, not less important. Hence, dynamic movements in and out of poverty have been found in a number of empirical studies (Beneke de Sanfeliu and Gonzalez-Vega, 2000; Moser and Barrett, 2003; Duflo, Kremer, and Robinson, 2006; Suri, 2011). An analysis of the influence of access to financial services on both the adoption and the abandonment of innovations may then help explain these dynamics of poverty.

Besides ignoring the dynamic process that drives the actual observations on technology adoption, reduced specifications often lack an underlying theory that guides the investigation. Besley and Case (1993) noted the difficulty that empirical models find in reflecting the underlying dilemma the farmers face, and they stressed the importance -for the design of optimal economic policies- of building models with microeconomic foundations. In an attempt to overcome some of these limitations, stochastic dynamic choice models are used in this paper to analyze technology decisions. These models not only provide sufficient theoretical strength to the study, but they also incorporate the time perspective needed to investigate poverty traps. The structure of the models analyzed in this research is similar to those of Fafchamps and Pender (1997), Dercon (1998), and Zimmerman and Carter (2003), although our focus is different, and therefore incorporates important distinctions.

By estimating the structural model, Fafchamps and Pender (1997) focused on explaining the effect of the irreversibility of a technology (wells) on the decisions of adoption. The main contribution of Fafchamps and Pender was to show that credit constraints can be a major obstacle for technology adoption, while the irreversibility is an additional but minor deterrent. We consider several financial regimes and allow for just access to credit, just access to deposit facilities, or both as well as different levels of financial deepening. This makes it possible to take into account the potential impact of different degrees of credit rationing and interest rate differentials. In particular, it makes it possible to compare the influence on adoption of different types of financial services. Also, since the technology they studied is irreversible, their study abstracts from dynamic movements across technologies. In our models the technology itself represents an illiquid asset that, although at a cost, may be reversed to face dreary circumstances.

The research of Dercon (1998) is not focused on studying financial mechanisms. Hence, he does not incorporate access to credit in the model, nor does he consider the influence of different levels of financial deepening. Further, he does not analyze the possibility of abandonment of the advanced technology. By studying the adoption of a lumpy investment, namely livestock, by subsistence farm-households, he provided empirical evidence that poor farmers tend to engage in low-risk, low-return activities. This result is also obtained by Zimmerman and Carter (2003), although their model differs from Dercon's in that it is one of portfolio choice, where the agents endogenously determine the prices of the assets and face a subsistence constraint.

In particular, Zimmerman and Carter (2003) calibrate an infinite horizon, dynamic, stochastic model, using Burkina Faso data. They impose a minimum level of (survival) consumption and endow the agents with heterogeneous levels of wealth, in order to track their portfolio choices -between a productive and risky asset (land) and an unproductive asset (grain)- over time. They find that, while initial, poor agents choose low-yielding portfolios, the wealthy accumulate additional productive assets. Based on the low-returns associated to the portfolio choices of the poor, they suggest that poverty traps are created. They conclude by suggesting that policies aimed at reducing risk would be productivity-improving.

Even though the approach in this paper is somewhat comparable to the work of Zimmerman and Carter, there are some key important differences. First, we do not impose a subsistence level of consumption, whose magnitude might highly drive the choice of low-return portfolios. While the presence of a minimum level -below which lower consumption would be unacceptable for the household- is a realistic stylized fact, the purpose of omitting it here is to allow farmers to optimally decide when and how much wealth to accumulate, which permits a better identification of other policy-relevant features that might otherwise be swamped by a rigid assumption in this connection.

Second, rather than quantifying optimal portfolio choices of continuous variables over time (where farmers could gradually accumulate the more productive asset), the models in this paper combine a continuous choice -how much to save and/or borrow- with a discrete choice -the adoption of one of the alternative technologies. It is the discrete choice over technologies that reflects the poverty traps that we investigate. As it will be shown in the

chapter of simulations, if the required investment for the advanced technology is low, poverty traps are hardly observed.

Although we do not impose a subsistence consumption level, we identify regions of low wealth where the marginal utility of present consumption is so high that household-farms are not willing to sacrifice current consumption by accumulating deposits, or by improving their balance sheet position. Thus, to emerge from poverty, households must first satisfy the high marginal utility of consumption, to only later reach a wealth position where accumulation or borrowing is done for investment purposes. Furthermore, the numerical results show that the extent of the regions is not sensitive to the size of lumpy investment and the risk associated to the advanced technology.

We find that access to credit has consistently a larger effect on adoption rates than access to deposits. It is only when the credit is serverly restrictive that deposits have a larger effect on adoption. In turn, access to deposit facilities is consistently more effective in preventing abandonment. When we simulate the economy with full financial deepening (the interest rate wedge between credit and deposit is zero), the adoption rates in the steady state increase with deposit facilities (the deposits become as efficient as credit), but barely change with only credit, which reflects a situation of true non-interest rationing. These findings provide foundations to better understand the dynamics of technology choices and help to design policies that facilitate the adoption and deter the abandonment of higher-productivity technologies.

The rest of the paper is organized as follows. Section 2 introduces a formal representation of the models. Section 3 presents the numerical approximations. Section 4 presents the numerical results, and Section 5 concludes.

2 Models of Finance and Technology Choices

We simplify the household-farm's decision over a potentially large number of technology choices by assuming that, in every period, the farmer engages in one of two productive activities available: one based on a traditional technology, $i = 0$, or one based on an advanced technology, $i = 1$. We assume, for example, that farmers produce a crop using either a traditional or a new improved variety. The new variety is, however, more susceptible to water availability and it requires a sophisticated sprinkler irrigation system, for which the farmer must make an initial relatively large investment, K.

The farmer faces an uncertain income stream, $\tilde{y}_i$, which depends on his choice of technology, i. We assume that farm incomes are lognormally distributed and serially independent, with mean $\bar{y}_i$ and volatility $\sigma_i > 0$. The advanced technology generates a higher expected income, $0 < \bar{y}_0 < \bar{y}_1$. However, since it is more vulnerable to water availability, while the farmer is experienced in the production of the traditional variety, production with the advanced technology is riskier, $\sigma_1 > \sigma_0$. The farmer then faces a trade-off between income-earning and risk.

The farmer begins each period possessing a pre-determined wealth, s, and invested in a given technology, i, which generates his production income for the current period. He must then decide whether to continue using the current technology or to adopt the alternative technology for the following period. This choice of technology is designated by j, and it requires the farmer to use a portion of his current wealth in anticipation of its use.

There is a per-period operational cost, κ_j, associated with employing each technology, j, and the advanced technology is more costly, $\kappa_1 > \kappa_0 \geq 0$, as it, for example, is energy intensive. These costs are incurred in the current period, for use of a technology, j, in the next period. As in Duflo, Kremer, and Robinson (2011), for example, the farmer purchases a stock of fertilizer now, to be able to produce and generate an income the next period.

In turn, the advanced-technology requirement for the irrigation equipment is a fixed capital investment to be made (once, at the time of adoption) in the current period, $K > 0$, for use in the next and future periods. A portion $\rho \in [0, 1]$ of this investment may subsequently be recovered, if switching back to producing with the traditional technology.

The total cost of choosing technology j for the following period, given that the farmer begins the current period employing technology i, is thus:

$$\tau_{ij} = \begin{cases} \kappa_j, & \text{if } i = j \\ \kappa_j + K, & \text{if } i = 0, j = 1 \\ \kappa_j - \rho K, & \text{if } i = 1, j = 0 \end{cases} \tag{1}$$

The farmer maximizes the present value of current and expected future utility of consumption over an indefinite time horizon, at a per-period discount factor $\delta \in (0, 1)$. The optimization problem solved by the farmer in a scenario a financial exclusion is summarized by the Bellman equation:

$$V_i(s) = \underset{j=0,1}{\text{Max}} \; u(s - \tau_{ij}) + \delta E V_j(\tilde{y}_j) \tag{2}$$

where the unknown value function, V_i, represents the maximum present value of the current and expected utility of a farmer currently engaged in technology i. Given his wealth at the beginning of the period, s, and his choice of technology for the following period j, the difference $s - \tau_{ij}$ represents the farmer's current consumption. Since the farmer is using technology i, switching his technology for the next period, j, is feasible only if $s > \tau_{ij}$. In the absence of any financial means to transfer wealth across periods, wealth next period, s, equals production income $\tilde{y}_j$.

The farmer's utility u exhibits constant relative risk aversion and is a twice, continuously differentiable function of current consumption, with $u^{'}(c) > 0$, $u^{''}(c) < 0$, and $u^{'}(0) = -\infty$.

So far, the model presumes that the farmer is fully excluded from financial markets. To capture the role of the financial mechanisms, a continuous choice variable is introduced to the model. Let x denote financial holding of the household. Additionally, a characteristic of poorly developed financial markets is a large gap between the interest rates charged on loans and the rates paid on deposits. To formally assess the differential effect of interest rates, we introduce in the model an indicator of financial deepening: $\psi = r_b - r_d > 0$, which is the difference between the interest rate charged on loans and the interest rate paid on

financial savings. A high ψ reflects substantial frictions and is associated with either shallow or repressed financial markets (Gonzalez-Vega, 2003). Formally, debt commands an interest rate r_b and deposits earn an interest rate r_d, where $r_b > r_d$. The one-period gross return on net financial holdings is:

$$g(x) = \begin{cases} (1 + r_b)x, & \text{if } x < 0 \\ (1 + r_d)x, & \text{if } x \geq 0 \end{cases} \tag{3}$$

Thus, when x is restricted to non-negative values, the model describes a situation where the farmer has access to deposit facilities, but he is excluded from credit markets. In turn, when x is restricted to non-positive values, the farmer has access to credit, but not to deposit facilities. When x is unrestricted in sign, the farmer has access to both credit and deposits facilities.

The farmer may deposit an unlimited amount, but he may borrow only up to a credit limit, $\bar{b}_j \geq 0$. Because the irrigation equipment represents collateral, the limit for the traditional producer is lower than for the advanced producer, $\bar{b}_1 > \bar{b}_0$. The assumption that $\min \{\tilde{y}_j\} > r\bar{b}_j$ implies that the farmer is not allowed to borrow so much that he might not be able to cover the minimum required interest payment the following period.

The difference between the rate charged on loans and the rate paid on deposits as well as the degree of credit rationing (given, in the model, by how binding the limits on loan sizes are, independently of the interest rate) characterizes poorly developed financial markets.

Incorporating these characteristics, the farmer's dynamic decision problem is characterized by the following Bellman equation:

$$V_i(s) = \underset{j=0,1 \;\; x \geq -\bar{b}_i}{\text{Max}} \; u(s - \tau_{ij} - x) + \delta E V_j(\tilde{y}_j + g(x)) \tag{4}$$

The value function, $V_i(s)$, represents the maximum expected present value of the current and expected utility of a farmer with given, s, and currently engaged in technology, i.

Each period, wealth, s, is allocated to consumption, net financial holdings, x, and the cost of investment and operation of the next period's technology, τ_{ij}. Wealth in the next

period equals production income $\tilde{y}_j$ plus the gross returns on net financial holdings $g(x)$, depending on the farmer's balance-sheet position.

At the aggregate level, the economy is composed of a large number of household-farms who behave as the representative farmer described so far, but who otherwise are heterogeneous with respect to wealth and technology state, as a result of having experienced distinct, idiosyncratic production shocks over time. In the steady state, there is a well-defined distribution of wealth and technology use across farmers. Let $F_i(s)$ denote the proportion of farmers in the economy who in the steady state are invested in technology i and have wealth less than or equal to s. Then, given that idiosyncratic shocks to production are fully diversifiable across agents in the economy, it must be that:

$$F_j(s') = \sum_i \int_{S_{ij}} G_j(s' - g_i(s)) dF_i(s) \tag{5}$$

where G_j is the cumulative distribution associated with production income $\tilde{y}_j$ and S_{ij} denotes the set of all wealth levels s, such that it is optimal for the agent to adopt technology j, given that he begins the period with wealth s and invested in technology i.

3 Conditional Value Functions and Optimal Policy Functions

The value functions described by equation (4) are approximated via the collocation method (Miranda and Fackler, 2002). This method converts the Bellman functional equation with no known analytical solution into a finite-dimensional nonlinear equation that can be solved using nonlinear equation methods such as Newton's or Broyden's method. Specifically, each value function $V(s)$ is approximated using a linear combination of M basis functions ϕ defined on the state space S, whose coefficients c are set by requiring the value function approximant to satisfy the Bellman equation at M collocation nodes $s_1, s_2, ..., s_M$. That is, we write $V(s) \approx \sum_{w=1}^{M} c_w \phi_w(s)$, where

$$\sum_{w=1}^{M} c_w \phi_w(s_m) = \underset{x \in (-\bar{b}_i, \infty)}{\text{Max}} \left[u(s_m, x) + \delta \sum_{h=1}^{H} \sum_{w=1}^{M} q_h c_w \phi_w \left(g(x) + \tilde{y}_{j,h} \right) \right] \tag{6}$$

where the continuous random income is replaced with a discrete approximation constructed by using Gaussian quadrature, such that H is the number of quadrature nodes and q_h is the probability of income $\tilde{y}_h$.

The collocation equation (6) is written as a root-finding problem and solved through Newton's method. In the process we employ polynomial splines basis functions. Because of the constraints of interest rate and credit limits in the Bellman equations, the solution for the maximization problem with respect to x are not stable using derivative-based methods. In order to find a solution, we specify a finite set of possible values of x. The best value of x is obtained by enumerating the value of the maximization problem for all possible values of x within that set. The residual functions are used to evaluate the accuracy of the numerical approximations. An approximation is considered acceptable when the residuals are near zero between the collocation nodes (Miranda and Fackler, 2002). Using the baseline parameter values presented in Table 1, the residual functions of the benchmark models are presented in the Appendix A.

The baseline parameter values shown in Table 1 are chosen to be within the ranges used in the literature (Fafchamps and Pender, 1997; Dercon, 1998; Zimmerman and Carter, 2001;

Table 1: Baseline Parameter Values and Range for Sensitivity Analysis

Parameter	**Base Value**	**Range**	**Description**
δ	0.85	0.83-0.90	Per-period discount factor
α	2.0	1.5-2.5	Relative risk aversion
$[\bar{y_0}, \bar{y_1}]$	[0.90,1.10]	–	Expected incomes
$[\sigma_0, \sigma_1]$	[0.25,0.33]	[–,0.23-0.35]	Income volatility
$[\kappa_0, \kappa_1]$	[0.11,0.13]	–	Production costs
K	1.0	0.30 - 1.10	Lumpy investment
ρ	0.50	0.25-0.75	Investmetn reversibility
r_d	0.02	[0.02 - 0.08]	Per-period interest rate on deposits
r_b	0.17	[0.08 - 0.17]	Per-period interest rate on loans
ψ	0.15	0.00 - 0.15	Wedge between interest rates
$[\bar{b_0}, \bar{b_1}]$	$[0.30, \bar{b_0} + 0.10K]$	$[0.0 - 0.40, \bar{b_0} + 0.10K]$	Borrowing limits

Miranda and Fackler, 2002). Time-preference and risk-aversion parameters are obtained from the preferred model of Fafchamps and Pender (1997).

The ranges of values displayed in Table 1 are the different parameter values used to explore: the extent to which riskiness (σ_1) and size of the lumpy investment (K) are able to capture poverty traps, the effects of credit limits ($\bar{b}$) and extent of financial deepening (ψ) on the choice of technologies, and the robustness of those results to different degrees of risk aversion (α), patience (δ) and technology reversibility (ρ).

Using the baseline parameter values, we examine four distinct scenarios: 1) full financial exclusion, that is, no access credit or deposit facilities; 2) access to credit, but not to deposit facilities; 3) access to deposit facilities, but not to credit; and 4) full financial inclusion, that is, access to both credit and deposit facilities.

The first scenario is used as a benchmark for the analysis of scenarios with partial/full inclusion. The second scenario characterizes an environment where household-farms, to accumulate wealth over time, can rely on access to deposit facilities and not just on their technology choices, but where they are completely excluded from the credit market. This scenario is similar to the financial structures found in other studies (Dercon, 1998; Dercon and Christiaensen, 2011). The third scenario implies that the farmer cannot save in financial form, in order to accumulate wealth from one period to another. This assumption represents the less frequently examined circumstances where, in the absence of deposit facilities, saving in kind is both quite costly and risky. Frequently, these costs and risks are high enough

to prevent the adoption of advanced technologies. Similar environments are empirically described by Duflo, Kremer, and Robinson (2006), Gomez-Soto (2007), and Dupas and Robinson (2011). In this scenario, the continuous choice variable represents the size of the loan, in contrast to the second scenario, where it represents the size of the deposit.

The results from these simplified models can be compared to the fourth scenario, which describes a situation where the household-farms have access to both deposit facilities and loans (while still being rationed). This comparison will be reported in the section on results.

3.1 Financial Exclusion

Figures 1 through 3 show state-conditional value functions described by equations 2 and 4. Each function represents the maximum value attained by a farmer who currently uses the subsistence traditional technology (left chart) or the modern advanced technology (right chart) and who decides to adopt the traditional (solid line) or the advanced technology (dashed line) for the next period, at different levels of wealth. The concavity of the functions portrays the underlying decreasing marginal utility of consumption implied by the form of the utility function.

Figure 1: Conditional Value Functions and Switch Points with Full Financial Exclusion

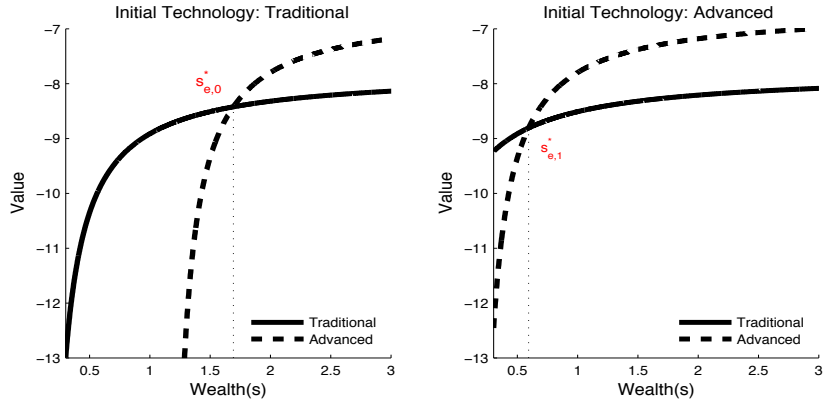


Figure 1 displays the state-conditional value functions for a financially excluded farmer. A traditional farmer finds it optimal to adopt the advanced technology only when the lifetime utility of being in subsistence production is lower than the expected lifetime utility of the alternative regime. The critical level of wealth at which this shift takes place corresponds

to the point $s^*_{e,0}$ (left chart). For lower levels of wealth, the farmer prefers to continue using the traditional technology while, for higher levels of wealth, the farmer adopts the advanced technology.

In turn, a modern farmer, already using the advanced technology, finds it optimal to abandon it only when the lifetime utility of keeping the advanced technology is lower than the lifetime utility when switching back to the traditional technology. The critical level of wealth at which this shift takes place corresponds to the point $s^*_{e,1}$ (right chart). At lower levels of wealth, the modern farmer will abandon the advanced technology.

In other words, the intersections of the conditional value functions at $s^*_{e,0}$ and $s^*_{e,1}$ correspond to the threshold levels of wealth at which it is optimal to adopt and to abandon the advanced technology, respectively. The value (1.69) indicates that, given the baseline values of the parameters, the farmer would want to have a level of wealth near 70 percent higher than the value of the minimum required investment, to be willing and able to adopt.

Thus, the "ability" to adopt (when the farmer attains a level of wealth sufficient to make the minimum investment) does not immediately lead to adoption because, for levels of wealth below the critical threshold, there is not "willingness" to adopt, since the opportunity cost in terms of current consumption would be still too high, given his inter-temporal preferences. However, given a diminishing marginal utility of consumption, if the level of wealth exceeds this threshold, the farmer gets more value from using the advanced technology (which represents a greater ability to consume in the future), and the switching occurs at the threshold.

In general, therefore, adoption requires not only that the farmer's level of wealth be sufficiently high to make the lumpy investment and incur higher operational costs but also to allow a level of current consumption that satisfies his inter-temporal preferences. These preferences reflect his impatience (discount factor) and degree of risk aversion.

In turn, abandoning the advanced technology is only optimal when the farmer's wealth falls below the threshold level corresponding to $s^*_{e,1}(0.59)$. This only happens if the level of wealth is so low that it is not sufficient to cover both the desired level of current consumption and the higher operating costs associated with the advanced technology. By abandoning the advanced technology, the farmer incurs lower production costs and earns a salvage return

from the earlier investment, which gives him the ability to sustain current consumption, at the level desired according to his inter-temporal preferences. Given this low level of wealth, the marginal utility of current consumption is too high to allow the sustainability of the advanced technology previously adopted.

A reversal of the choice (from the advanced to the traditional technology) thus reveals unusually dire circumstances, and instruments to prevent the abandonment of the advanced technology should be welfare-enhancing. The following two scenarios explore the role that access to different kinds of financial services play in preventing this abandonment.

3.2 Partial Financial Inclusion: Only Access to Deposits

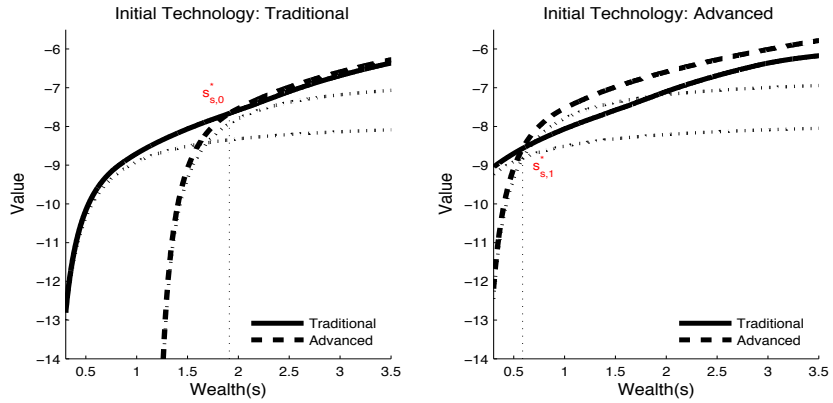
The farmer makes choices that attempt to approximate combinations of current and future consumption that maximize his lifetime utility, given his constraints. To generate an income that allows consumption in the future, however, the farmer must sacrifice some current consumption. In the absence of deposit facilities, as in the case of full financial exclusion, he must hold these savings in kind. In the model, when the farmer makes a technology choice in the current period, he allocates a portion of his current income to the purchase of some operational inputs and -when first adopting the advanced technology- to an investment in a lumpy capital good. These inputs purchased in advance will then generate next period's income. In the model, the costs of the operational inputs associated with each technology as well as the investment in the irrigation system are given as a fixed amount. Thus, each choice of technology is also a savings decision, and the farmer consumes the difference with his current income.

For each choice of technology, the amount of savings is given, as each package of operational inputs is not liquid (it is indivisible). Because of this indivisibility, current consumption -as the residual- may not necessarily be the amount to be chosen when saving were a continuous rather than a discrete choice. When the opportunity to make a deposit emerges, however, the farmer acquires a liquid instrument for holding his savings. This continuous choice allows him to more closely approximate his optimum combination of current and future consumption. This should increase his utility for all of those levels of wealth for which the deposit facility is relevant -that is, when the farmer's wealth is sufficiently large for him

to be able to purchase the package of inputs, consume at his inter-temporarily optimum level, and save an additional amount to be held in a bank deposit. This is the "liquidity" effect of the availability of deposit facilities. Further, as the farmer now earns an interest on his deposit, his future income increases from the earnings on the deposit, and this allows a more satisfactory choice next period. This is the "wealth" effect of the availability of deposit facilities.

The farmer's ability to accumulate deposits may thus encourage the adoption of the modern, advanced technology (investment motive) and reduce the chances of its abandonment (precautionary motive). Figure 2 shows the value functions for a farmer who has access to deposit facilities, but not to loans. The value functions for the case of full financial exclusion are also plotted (dotted lines), to facilitate the comparison.

Figure 2: Conditional Value Functions and Switch Points with Deposits



In the left panel of Figure 2, these effects are shown -for a farmer using the traditional technology- as an upward shift of the value function, for levels of wealth above some minimum value for which the deposit facilities are relevant (that is, the solid line is above and it increasingly diverges from the dotted line). For levels of wealth lower than this minimum and given the indivisibility of the input package (even in the case of the traditional technology), the farmer does not achieve the level of current consumption that he would have chosen under divisibility and, therefore, there are no financial savings. Thus, the value function when there are deposit facilities is above the corresponding function for full financial exclusion once the farmer accumulates some financial savings, because he is above this minimum level of wealth (consumption threshold).

A portion of the difference between these two value functions is due to the liquidity effect, and it would be present even if the interest rate paid on deposits were zero, given the utility-enhancing effect of liquidity. The other portion represents the greater ability to consume due to the additional income generated from interest earnings. Thus, the higher the interest rate, the more will the value function diverge from the one corresponding to full financial exclusion.

Nevertheless, naught utility gains are derived from having access to deposit facilities when the farmers are sufficiently poor, with levels of wealth below the minimum level (consumption threshold) described above, and they face an indivisible package of inputs. The cost of these inputs may represent more than these farmers would have liked to save, but these savings in kind are unavoidable because the farmer must generate an income in the following period. Having deposit facilities available, therefore, does not make a difference for these extremely poor farmers. This result is confirmed by the policy functions in Figure 3. The horizontal segments of the optimal policies indicate the levels of wealth at which the deposits are zero.

Once the farmer's level of wealth is sufficiently high for him to choose some amount of financial savings, the gains in utility ?compared to those under full financial exclusion? are increasingly higher as he becomes less poor. In fact, the marginal utility of an extra unit of wealth (given by the slope of the value functions) is higher when there are deposit facilities, compared to the case of full financial exclusion.

As shown in Figure 2, because of the upward shift of the value function, the adoption threshold is substantially higher in this scenario ($s^*_{s,0} = 1.91$) than under full financial exclusion. This means that, once a deposit facility makes financial savings possible -as an alternative for carrying purchasing power over the next period- the farmer would be willing to adopt only at higher levels of wealth. That is, for some levels of wealth above $s^*_{e,0}(1.69)$, which is the threshold for the case of full financial exclusion, additional accumulation of savings in a deposit is a more attractive way of generating a future income than the adoption of the advanced technology. This is no longer the case for levels of wealth above ($s^*_{s,0} = 1.91$). Furthermore, this result is robust to the different parameter simulations.

A higher wealth threshold for adoption in the case with deposit facilities reflects the farmer's unwillingness to sacrifice a large amount of current consumption by rushing into

adoption, which requires a lumpy investment, but instead his willingness to sacrifice a smaller amount of current consumption, because of the availability of the liquid deposit instrument. At levels of wealth above the threshold, the sacrifice of the lumpy amount of savings becomes attractive, given the increase in future consumption that adoption promises.

Further, in the case without financial services, adoption entirely depends on having a good year, with a sufficiently high income (which is a random event), and, unless the farmer goes ahead with the switching at that time, adoption might never materialize or it may only occur at some uncertain, future period. Thus, the farmer is more willing to adopt at lower levels of wealth than when there are deposit facilities. Thus, access to deposits offers the farmer some control over the timing of the adoption, through the accumulation of liquid financial savings. Adoption in this case occurs only after the farmer feels sufficiently satisfied with his level of current consumption (inter-temporal optimization), rather than leaving the switching to the fortuitous circumstance of a particularly good harvest and being forced to adopt too soon and at too high an opportunity cost.

Given the random nature of income, moreover, a lower wealth threshold for the case of full financial exclusion does not necessarily imply that adoption occurs sooner in this instance or that the levels of adoption in an economy are lower when institutional financial services are offered, as will be shown below. On the contrary, unlike in the case of full financial exclusion, access to deposit facilities ensures that households have the opportunity to save enough to afford the adoption.

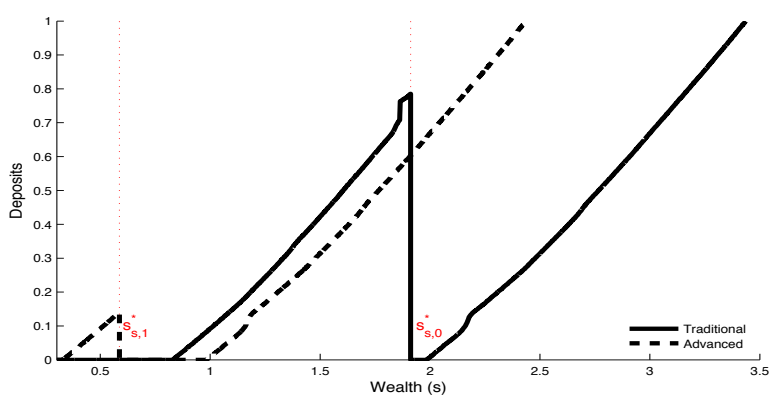
The right panel of Figure (2) shows the state-conditional value function of a farmer who is already producing with the advanced technology. It shows that the threshold for abandonment is approximately the same ($s^*_{s,1} = 0.59$) as in the case of full financial exclusion. The literature suggests that access to deposit facilities allows farmers to tolerate a greater reduction in wealth before it becomes optimal to abandon the advanced technology. The finding here that the threshold level of wealth for abandonment is not lower than under full financial exclusion is not inconsistent with this literature. The simulations reported below indicate that the farmer's ability to accumulate a deposit reduces the chances of suffering a catastrophe. So, while it is true that the threshold remains more or less unchanged, it is less likely that a farmer with deposits would reach this low threshold than without them.

Analytically, this is explained by the fact that abandoning the advanced technology in an environment of full financial exclusion reduces the farmer's utility by a considerably larger amount than when there is access to deposits. While this less-studied effect may seem less substantial, it may be quite relevant in an environment of volatile incomes, where household-farms that have escaped a poverty trap may easily fall into one again.

For a deeper exploration of the household-farm behavior over deposits, the optimal policy functions are presented in Figure 3. These functions offer concrete insights about how and when access to deposit facilities influences the emergence from poverty traps. Whether the farmer is using the traditional (solid line) or the advanced technology (dashed line), the policy functions confirm that, at sufficiently low levels of wealth, the optimal decision is not to accumulate deposits.

The incentive to accumulate financial savings is explained by the liquidity properties of deposits and by their wealth effect. The traditional farmer not only saves for precautionary motives, however, but also for investment purposes. Thus, the traditional farmer deposits a larger amount than the advanced producer. Right at the adoption threshold ($s^*_{s,0}$), when the traditional farmer is willing and able to purchase the irrigation equipment, the optimal policy displays a drop in his deposits. It is at this wealth level when the farmer decides to withdraw a large portion of his deposits, in order to purchase the new technology and engage in the advanced production. The optimal saving policy is no longer depicted by the blue line, but by the green one.

Figure 3: Optimal Policy Functions of the Model with Deposits



The smaller peak at ($s^*_{s,1}$) of the optimal policy function for the modern farmer is the

salvage value of the investment, recovered when abandoning the advanced technology. It reflects dismal situations, where the farmer can no longer sustain the advanced technology and prefers to resell the equipment. When the farmer reaches this low level of wealth, he optimally chooses to return to the traditional technology.

A region of low wealth, where the presence of deposit facilities is fruitless, is nontrivial. If the farmer is not able or willing to move away from this region, adoption, as in the case of full financial exclusion, depends only on fortuitous circumstances (an unusually favorable production shock) rather than on the farmer's plan to adopt. Once the farmer moves away from this region, however, he does not immediately adopt. Higher levels of wealth allow him to accumulate deposits and earn an interest, but wealth would have to increase even further, until it reaches the adoption threshold, for the farmer to start using the advanced technology.

3.3 Partial Financial Inclusion: Only Credit

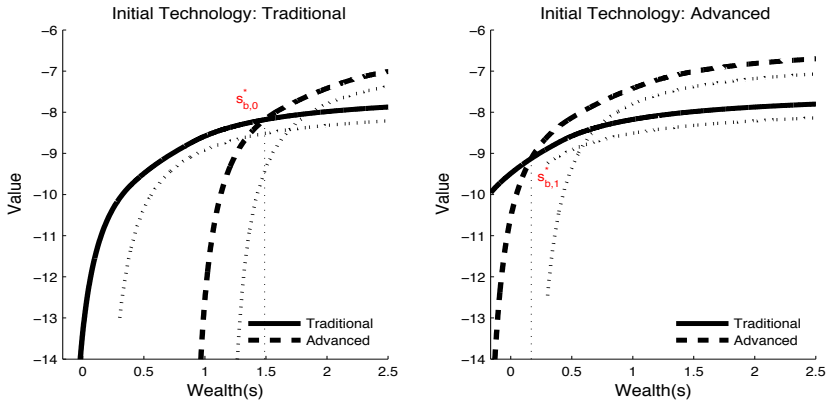
To compare the effects of full financial exclusion and of just access to deposit facilities versus access to just borrowing, in this scenario the value functions are approximated by allowing the traditional farmer to borrow up to 30 percent of the cost of the irrigation equipment (0.3 units). Additionally, once the farmer has adopted the advanced technology, the irrigation equipment can be pledged as collateral and, therefore, this borrowing limit is augmented.

In the absence of opportunities to accumulate deposits, as in the scenario of full financial exclusion, the farmer can only save via the adoption of the illiquid technology package, with the limitations that holding savings in kind imply. Thus, the liquidity and wealth effects that a liquid deposit instrument provides disappear. Nevertheless, while deposits become relevant only after a farmer's fixed-coefficient production requirements and then his inter-temporal consumption preferences are met, in contrast, at every level of wealth, access to credit allows the farmer to approximate a more inter-temporarily satisfactory allocation of his wealth.

That is, large enough loans expand the farmer's budget constraint sufficiently to allow the purchase of the required indivisible inputs and, at the same time, achieve an inter-temporally optimum level of current consumption, independently of his level of wealth. In this environment, therefore, the loan has essentially a consumption smoothing role.

As a result, with access to credit, the level of lifetime utility increases at all levels of wealth, compared to full financial exclusion. The corresponding upward shift of all four value functions is observed in both panels of Figure 4. The benefits lost with exclusion from the market for deposits are reflected by the more concave value functions, when compared to the case with just deposit facilities. The utility gains from just access to credit are displayed by the amount of the upward shift of the value functions.

Figure 4: Conditional Value Functions and Switch Points with Credit



As a consequence of the greater ability both to consume and to adopt the advanced technology offered by a loan -compared to the previous two scenarios- both thresholds of wealth (to adopt the advanced technology and to abandon it) fall, to $1.48(s^*_{b,0})$ and to $0.17(s^*_{b,1})$, respectively. In this case, to be able and willing to adopt, the farmer no longer needs a level of wealth roughly 70 percent higher than the cost of the investment required for adoption of the advanced technology (given the parameter values for the baseline), but only a level of wealth about 48 percent higher than that cost.

Thus, it seems that the gains (in terms of adoption rates in the economy) from the incorporation of farmers into credit markets may be greater than those associated with just access to deposit facilities. However, since the farmer must repay the loan, reaching the adoption threshold may be more difficult under this scenario. If the interest rate on loans (which, here, represents all of the interest and non-interest costs of borrowing) is low and the credit limit high, the lower adoption thresholds could indeed materialize in higher adoption rates in the economy. These features will be explored when the aggregate economy is simulated. In addition to the impact of the interest rate, the simulations show that how

much this threshold falls with access to loans depends on the restrictiveness of the credit limit (that is, on the extent of credit rationing).

For the advanced producer, the benefit of access to credit and of a higher credit limit, since he can pledge collateral, is immediate as he can avoid abandonment unless his level of wealth reaches down to 0.17 units ($s^*_{b,1}$), as compared to 0.59 in the cases of full financial exclusion or of just deposit facilities (right panels of Figures 1 and 2).

For the advanced producer, the effect of the augmented credit limit is clear in Figure 5 (dashed line). Pledging the equipment as collateral allows him to borrow a larger amount and, after acquiring the required production inputs, he can consume more. Also, because after adoption he no longer has an investment motive, he borrows at the maximum credit allowance (0.40) exclusively to satisfy his inter-temporal consumption preferences. The loan thus allows the farmer to bear a greater wealth reduction and still remain in the advanced technology regime.

For a given credit limit, however, when the levels of wealth are sufficiently low (less than 0.17), the amount available for consumption -after covering the costs of the advanced technology- would be too low, given the farmer's inter-temporal preferences. Due to a high marginal utility of consumption at these low levels of wealth, the farmer is not willing to sacrifice so much current consumption, in order to maintain a more expensive technology, so abandonment takes place. Thus, loans that sustain consumption, in the presence of the income risk associated with production using the advanced technology, may be critical for its successful and sustained adoption. Credit for consumption smoothing is therefore critical to prevent abandonment.

The optimal borrowing policies shown in Figure 5 uncover regions of wealth equivalent to those of zero demand for deposits discussed in the previous scenario. At very low levels of wealth, the region of zero deposits is mirrored here by a region where the farmer cannot improve his balance-sheet position.

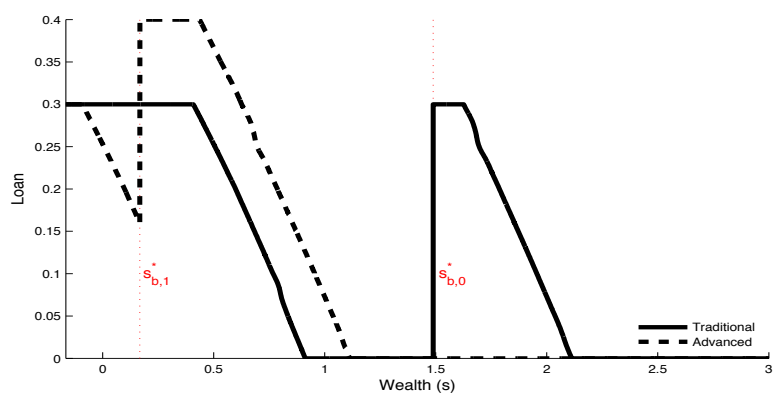
A policy implication of this behavior is that, when credit is targeted to very poor farmers who use a traditional technology, not only they may not adopt the advanced technology (because their wealth level is below the corresponding threshold), but also they will not be able to reduce the amount of credit borrowed. This assumes that lenders are content

with this arrangement. Otherwise, credit rationing would be even more restrictive. Farmers would only begin to improve their balance sheet position when external circumstances (a positive shock) bring them to a more favorable wealth position.

This result may help to explain the null effect of loans on business investment, found in some settings (Karlan and Zinman, 2009). It may also explain the somewhat disappointing results regarding the effect of insurance on credit up-take rates found by Gine and Yang (2009) and Karlan et al.(2010). Insuring against adverse shocks in the production income associated with the advanced technology should make adoption more attractive, thereby reducing the adoption wealth threshold (that is, the dashed curve in the left panel of Figure 4 would be less concave because of the lower risk), but this only benefits those farmers with a sufficiently high level of wealth to be willing to adopt.

An advanced producer who experiences a serious reduction in wealth, below the threshold for abandonment ($s^*_{b,1}$), is better off by switching back to the traditional technology. At this level of wealth, $s^*_{b,1}$, he recovers part of the initial investment (salvage value) and returns to a wealth position where he stays away from the region where he cannot improve his balance-sheet position.

Figure 5: Optimal Borrowing Policy Functions



To assess how these thresholds affect the rates of adoption and abandonment under the three different scenarios of financial inclusion and different parameter values, I undertake some simulations for critical values of the relevant parameters.

4 Numerical Results

We expand the representative farmer's dynamic optimization models solved in the previous chapter to allow for a large population of farmers who behave as the representative farmer, but who otherwise are heterogeneous with respect to wealth and technology choice, as a result of having experienced distinct, idiosyncratic production shocks over time.

The results at the aggregate level are reported in this section. The main objectives are:
(i) To explore the extent to which the riskiness and investment lumpiness of the advanced production technology are able to explain poverty traps.
(ii) To examine the effects of various dimensions of financial development on the steady-state adoption rates. First, we compare the effects of the three distinct scenarios of financial exclusion/inclusion. Second, we explore the effects of different levels of the credit limit. Next, we incorporate a scenario of full financial inclusion and compare it with the three base scenarios of full exclusion and partial financial inclusion. Finally, we explore the effects of different degrees of financial deepening, by simulating the economy at different levels of the interest rates.

4.1 Traps Associated with Risk and Investment Level

Poverty traps arise from the high income risk associated with the advanced technology or the lumpiness of the investment needed to adopt it. We examine these two barriers to adoption in turn.

Risk

To evaluate the influence of the riskiness associated with each technology in creating a poverty trap, we solve the models for regimes of relatively low and relatively high income volatility for the advanced technology. An advanced technology with "low volatility" represents an opportunity that not only is more profitable but is also less risky than the traditional technology. It dominates the traditional technology in every respect, but it may not be adopted if it requires a large lumpy investment or if the farmer's wealth lies in the zero-deposit or zero-repayment regions. An advanced technology with "high volatility" also shows higher

returns than the traditional technology, but it is more risky.

As shown in Table 1, in order to implement these simulations, we modify the variance of the expected income associated with the advanced technology, from 0.23 (which implies less volatility than for the income generated with the traditional technology, where the variance is kept at 0.25 units) to 0.35 (which implies more income volatility than with the traditional technology). All other parameters are kept at their baseline values.

Table 2 shows the switching thresholds of wealth for the different income volatility levels. These threshold outcomes and the associated steady-state rates of adoption are consistent with a literature that suggests that reducing the volatility of the expected incomes resulting from the application of the advanced technology may encourage its adoption (Fafchamps and Pender, 1997; Zimmerman and Carter, 2003; Dercon and Christiaensen, 2011). Similarly, the results suggest that, when the advanced technology becomes riskier, the risk-averse farmer would switch back to the traditional technology at higher levels of wealth than otherwise.

Hence, when the advanced technology guarantees a higher expected income and lower risk (that is, when it dominates the traditional technology in both respects), the majority of the farmers eventually end up engaged in production with the advanced technology (at least over 87 percent of them), in each of the three financial development scenarios. Thus, with low production risk, a poverty trap is not captured.

In contrast, when the advanced technology is highly risky (riskier than the traditional technology), *ceteris paribus*, the adoption rates decrease to 30 percent of the farmers, when only credit is available, to 21 percent of the farmers, when only deposit facilities are available, and to 7 percent of them, in the case of full financial exclusion.

At the aggregate level, under steady state, "adoption rates" are defined here as the proportion of the population of household-farms that uses the advanced rather than the traditional technology. In a particular empirical context, this rate of use of the advanced technology includes all those farmers that had previously adopted and had not abandoned the advanced technology as well as those who strictly adopted it in the period under observation. This distinction becomes relevant for the econometric exercises below.

The average time required for the first adoption (when a particular household-farm for the first time switches from the traditional to the advanced technology) is also shown in

Table 2: Risk and Investment Level Effects on Poverty Traps

	Baseline	Risk		Investment	
		Low	High	Small	Large
Wealth Thresholds					
(units of wealth) ***Adoption***					
Deposits, no credit	1.91	1.75	1.94	0.96	2.11
Credit, no deposits	1.48	1.37	1.50	0.65	1.60
Exclusion	1.69	1.58	1.71	0.98	1.80
Abandonment					
Deposits, no credit	0.59	0.53	0.59	0.52	0.60
Credit, no deposits	0.17	0.10	0.18	0.14	0.18
Exclusion	0.59	0.50	0.60	0.55	0.60
Steady-State Adoption Rate *(%)*					
Deposits, no credit	27	96	21	99	9
Credit, no deposits	38	97	30	99	18
Exclusion	8	87	7	92	4
Abandonment [a]					
Deposits, no credit	2.92	0.09	3.8	1.38	3.46
Credit, no deposits	3.27	0.08	4.3	1.19	4.19
Exclusion	11.4	0.12	14.1	8.58	13.3
Average Time for Adoption					
(Number of Periods)					
Deposits, no credit	118	71	123	4.6	141
Credit, no deposits	99	60	104	4.7	127
Exclusion	124	95	127	5.1	135

[a] *Average number of times the technology is reversed divided by the steady state rate of adoption*

Table 2, and it helps in describing the process of reaching the steady state. The results indicate that, although -in the steady-state- the rate of adoption (use) is near 100 percent, when the advanced technology carries a low risk, the first adoption takes, on average, around 95 periods, in the case of full financial exclusion. This time for adoption declines to around 70 periods when only deposit facilities are available and to around 60 when there is just access to credit (Table 2). This indicates that, while the steady-state adoption (use) rates are similar in the cases of partial financial inclusion than in the case of exclusion, the time required to reach the steady state is shorter in the presence of credit or deposits.

Financial services are less effective in overcoming the barriers to adoption when risk is high than when it is low. In general, however, access to financial services significantly reduces

the time needed for adoption of the advanced technology. Moreover, access to just credit is consistently more effective (in facilitating adoption sooner and in encouraging higher rates of adoption) than just deposit facilities are. In turn, however, when the income associated with the advanced technology is more volatile, access to only deposit facilities appears to be more effective in preventing abandonment of the advanced technology, compared to only access to credit.

Investment

We explore the extent to which a poverty trap results from the size of the lumpy investment required to adopt the advanced production technology, through a parametric analysis of the amount of the investment. In Table 2, the small investment characterizes a comparatively divisible technology, where the farmer can acquire the improved variety by borrowing at his credit limit or through a fast accumulation of deposits. In turn, a large investment characterizes an indivisible technology, where the amount needed requires a long period of prior accumulation or a very high credit limit. Typically, it cannot be financed with only credit. In either case, the salvage value of the investment may be thought of as the associated implicit insurance in case there is a severe adverse production shock that forces abandonment of the advanced technology.

We simulate the value of the lumpy investment required for adoption of the advanced technology at a small (0.3) and a large value (1.1). The large differences among the threshold values of wealth associated with adoption and among the steady-state rates of adoption (Table 2) indicate that the amount of the lumpy investment required to adopt the advanced technology plays a fundamental role in determining the proportion of the rural population trapped in low-return technologies. The significant reduction of the adoption thresholds when the required investment is small (that is, with increased divisibility) is the result of the lower current consumption sacrifice associated with adoption in that case. Clearly, when the hurdle is higher, the farmer should require more wealth in order to adopt the advanced technology. Similarly, times for adoption are much shorter when the required lumpy investment is small.

Compared to a loan, a process of accumulation, through deposits, makes it more difficult to generate the required resources for adoption and the accompanying desired level of

consumption. This is because the interest rates paid on the deposit are low and because, at sufficiently low levels of wealth (in the region of zero deposits), the farmer is not willing to demand the deposit facility and accumulate financial savings, beyond the resources (inputs) needed to implement a given technology in the following period. Thus, the adoption hurdle seems to be overcome more easily and willingly when there is access to loans only than in the case of just access to deposit facilities (Table 2). This result may not be robust, however, if very strict credit rationing is adopted by the lenders (a very low credit limit, as may be the case with some microfinance programs), as we will explore in the next section.

The increase in the wealth thresholds for abandonment of the advanced technology, for the larger lumpy investment, responds to the lesser utility associated with the smaller salvage value of low-value investments. Since, in the model, the farmer always has the option of reselling the asset associated with his investment, this salvage value determines how low a level of wealth the farmer will be willing to bear before deciding to get rid of the advanced technology. Thus, when the farmer can recover a larger portion of the cost of the investment or when the value of the investment is larger, he will not switch back to the traditional technology unless his wealth becomes low enough. However, at sufficiently low values of wealth, the limitations on his consumption and the high marginal utility of current consumption will induce him to take the salvage value and abandon the advanced technology. In contrast, when the value to be recovered is small, he would rather face the lower income generated by the advanced technology, in case of an adverse shock, than switch back to the traditional technology. Indeed, the average time the farmer takes to return to production with the traditional technology seems to be shorter when the lumpy investment is larger.

Thus, given the base values of the parameters, the overall rates of adoption (use) in steady state are higher when the lumpy investment has a lower cost. Even in a regime of full financial exclusion, when the minimum investment is small the adoption rates are near $100 percent$. Therefore, the results shown in Table 2 verify that low risk and small investment levels do not sufficiently capture poverty traps.

In the following analysis of the influence of various dimensions of financial development, both risk and investment levels are kept at their baseline values. Table 2 reports results associated with these baseline values. Given the critical wealth thresholds resulting from

the household behavior analyzed in the precious chhapter, two major results deserve special attention.

First, access to just credit has a larger impact on adoption (use) rates than just access to deposit facilities. Second, access to deposit facilities is more effective at reducing abandonment than credit. While the latter result persists in most of the simulations, the larger effect of credit -compared to deposits- depends on the value of key parameters.

For instance, a change in time preferences may affect the comparative effectiveness of credit and deposits. At its baseline value, $\delta = 0.85$ characterizes somewhat impatient households. This value is a fair characterization of rural environments (Fafchamps and Pender, 1997), but more patient household-farms (with a higher discount factor) would be more willing to sacrifice current consumption by accumulating deposits. As a result of this change in time preferences, access to deposit facilities may outperform access to credit in inducing adoption of the advanced technology (Appendix B). In contrast, more impatient household-farms would use loans to adopt at lower levels of wealth.

Because of their importance in characterizing different levels of financial development, the effects of borrowing limits and interest rates are analyzed in the next section. A full set of simulations from changes in other parameters is included in Appendix B.

4.1.1 Credit Rationing

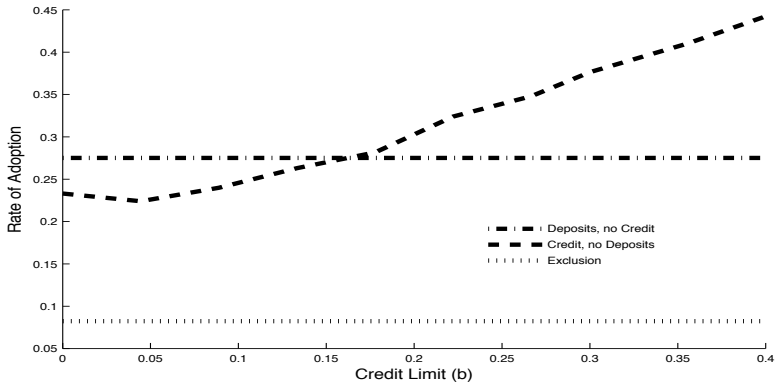
The distribution of farmers over the two technologies -in the steady state- is depicted in Figure (6), for different levels of the credit limits. The results show that severe credit rationing reduces the ability of farmers to engage in high-risk, high-return production with the advanced technology. In effect, the percentage of advanced-technology producers increases with the credit limit.

The reason why more restrictive credit conditions reduce adoption rates is that a small loan may not be sufficient to satisfy the farmer's inter-temporal consumption aspirations, cover the costs associated with implementation of the advanced technology, and leave enough wealth to repay the loan. In addition, compared to a larger loan, the sacrifices of future consumption needed for repayment are smaller, so the farmer is still willing to hold some debt at higher levels of wealth. Whether cheaper or more expensive credit changes these

adoption rates will be explored below.

The simulations also suggest that the availability of deposit facilities is more effective than credit in inducing adoption in the case of sufficiently severe credit rationing. Notice that, when the credit limit is below 16 percent of the size of the lumpy investment, the percentage of farmers producing the advanced crop is higher under the scenario of only deposits than with just credit (Figure6)

Figure 6: Credit Limit Effect on Steady-state Distribution over Technologies



Note that because the adoption rates shown in Figure 6 are for the steady state, it may be possible that in the short run farmers indeed struggle more in adopting when their debt is large but, once they have adopted, the higher credit limit would allow them to sustain the advanced technology. To shed light on this issue, Figure 7 illustrates the average time for adoption for each credit limit and each type of financial service.

Figure 7: Credit Rationing Effect on Average Time for Adoption

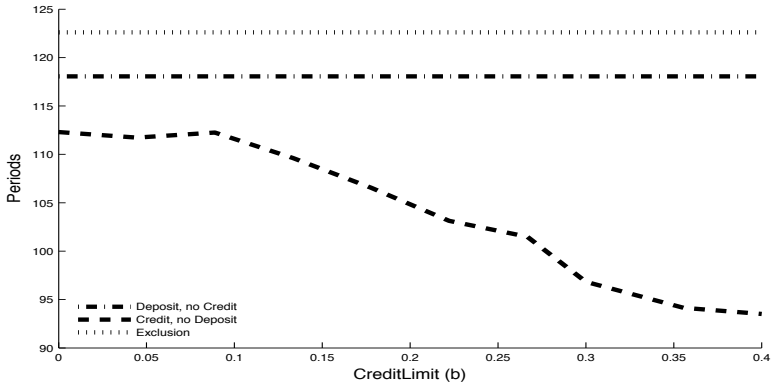
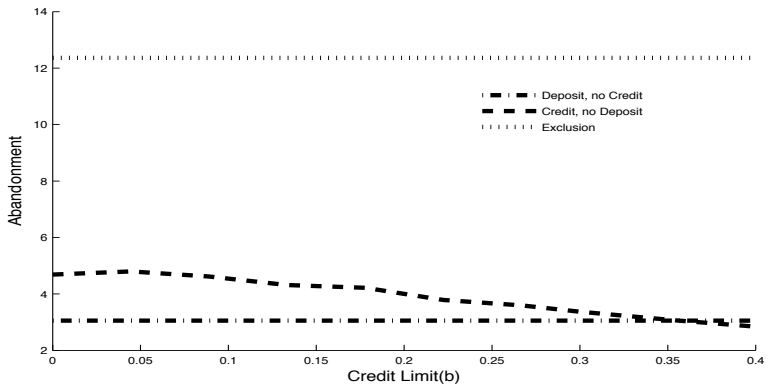


Figure (7) confirms that less constraining credit limits indeed facilitate adoption. When

farmers are almost excluded from the credit market (the borrowing limit is close to zero), the average time for adoption is above 110 periods; when the credit limit is increased to 40 percent of the value of the lumpy investment, the average time for adoption goes down to less than 95 periods. Furthermore, even when the credit limit for the traditional producers is near zero, on average, they adopt faster than when they are fully excluded from the credit market or only have access to deposit facilities.

The implication of credit rationing for the farmers' ability to sustain the advanced technology is displayed in Figure (8). With the metric of abandonment used here, the graph shows that, unless the credit limits are sufficiently large (approximately 35 percent of the lumpy investment size), the number of times a farmer will abandon the advanced technology will be lower with access to just deposit facilities than with just credit.

Figure 8: Credit Rationing Effect on Technology Abandonment



It appears that when the credit limits are quite constraining, access to deposit facilities is more effective in facilitating the sustained adoption of the advanced technology than access to credit.

4.1.2 Financial Inclusion

Table (3) summarizes the minimum levels of wealth for adoption and abandonment of the advanced technology, for the three financial scenarios, namely, (1) when the farmer is financially excluded, (2) when he has access to deposit facilities but is excluded from credit access, and (3) when he has access to loans but is prevented from accumulating financial holdings

through a deposit facility. The last column in Table (3) presents the values of a scenario of full financial inclusion.

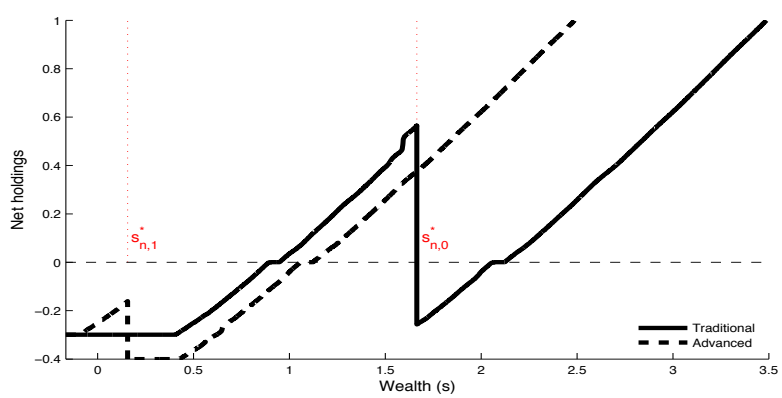
Table 3: Wealth Thresholds for Adoption and Abandonment at Baseline Values, for several Financial Market Regimes

Threshold	**Exclusion**	**Only Deposit**	**Only Credit**	**Inclusion**
Adoption	1.69	1.91	1.49	1.66
Disadoption	0.59	0.59	0.17	0.16

The wealth thresholds for adoption and abandonment under a scenario of full financial inclusion depend on the curvature of the farmer's state-conditional value functions. On the one hand, as a result of having the opportunity to accumulate deposits, the farmer obtains the benefits that this liquid financial instrument provides. Thus, the value functions are less concave (as in the deposits only scenario). On the other hand, as a result of having the opportunity to borrow, with the possibility of better satisfying inter-temporal consumption preferences and covering the operational costs of the technology, at all levels of wealth, the value functions shift upwards (as in the just credit scenario).

The optimal policy function mirrors the borrowing policy when the optimal level of net holdings is negative and the depositing policy when this level is positive (Figure 9). Together, these results imply that the wealth threshold for adoption is contained within the range defined by the thresholds corresponding to the presence of each one of the two financial services, when considered separately ($s^*_{s,0} > s^*_{n,0} = 1.66 > s^*_{b,0}$).

Figure 9: Net Financial Holdings Optimum Policy Function with Full Financial Inclusion



In contrast, the wealth threshold for abandonment does not lie in between, but it is

similar to the threshold for abandonment in a regime with only credit, $s^*_{n,1} = 0.16$. This is because abandonment occurs at levels of wealth were the demand for deposits is zero, so the thresholds for abandonment only reflect the effect of borrowing. This threshold is low enough to allow the advanced producer to tolerate even more severe reductions of wealth than he would under the other scenarios.

Notable features of the net-financial holdings policy functions are the horizontal portions of the function for some levels of wealth (between 0.8 and 1.2), where the farmer is neither willing to deposit nor to borrow at the current financial conditions (recall that $\psi = 0.15$). This unwillingness emerges precisely from the presence of a wedge between the interest rates paid on deposits and the rates charged on loans and it is, therefore, a consequence of the insufficient development of the financial market.

Unlike the zero-repayment, zero-deposits regions found earlier, where the inability or unwillingness of the farmers to deposit (or improve the balance sheet position) emerge from the high value of the marginal utility of current consumption at low wealth levels, in these zero-deposits and zero-borrowing regions, the farmer has reached a level of wealth high enough to be able to borrow or to deposit, but he is not willing to do so.

For the traditional farmer, this behavior indicates that he has become wealthy enough to maintain a comparatively high consumption level without having to apply for credit, but in which the conditions of the market for deposits (low interest rates paid) are not sufficiently attractive for him to accumulate deposits, in order to increase his future consumption. That is, neither the liquidity nor the wealth effects of the deposit makes the expected present value of lifetime utility sufficiently large for the farmer to use deposit facilities.

For the farmer using the advanced technology, this region of zero deposits, zero borrowing may be interpreted as the farmer's unwillingness to borrow, due to its high cost. It is only when his level of wealth has fallen sufficiently low (where, to maintain the advanced technology without credit, his sacrifice in reducing current consumption would become intolerable) that he begins to borrow. In general, therefore, incomplete financial markets, characterized by high transaction costs that create a wedge between deposit and loan interest rates, shrink the demand for both deposit facilities and loans. Improvements in financial markets, represented by a reduction of this wedge, would make borrowing and depositing more attractive

and would increase the farmer's utility.

Financial inclusion of the farmer in both the credit and deposit markets increases the adoption rate of the economy -in the steady state- to 50 percent, as compared to the scenario of full financial exclusion (with an adoption rate of 8 percent), only access to deposits (27 percent), and only access to credit (38 percent). To further examine how financial inclusion and different interest rates influence adoption and prevent abandonment, compared to the base scenarios, I simulate the economy for each of these scenarios and report the results in the next section.

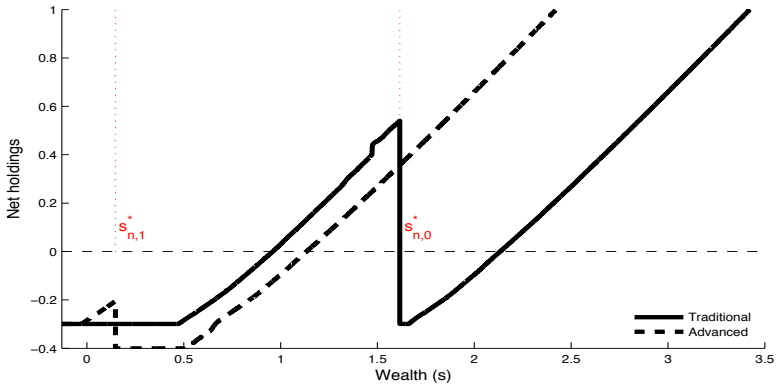
4.1.3 Financial Deepening

The extent of financial deepening is captured by the difference between the interest rates paid on deposits and charged on loans. At their baseline value, the interest rate paid on deposits is near zero ($r_d = 0.02$) and the rate charged on loans is high ($r_b = 0.17$). This, in turn, implies scant financial deepening, with a wedge of ($\psi = 0.15$). To explore how full financial deepening changes the adoption rates in the economy, both the interest rate on borrowing is lowered and the interest rate on deposits is increased to 8 percent, eliminating the wedge ($\psi = 0$).

The optimal policy function for a farmer with access to both credit and deposits at the same interest rates (full financial development) is displayed in Figure 10. As a result of full financial deepening, deposits and credit become worth using at all levels of wealth; that is, the zero-deposits, zero-credit regions found in the analysis of the net financial holdings policy functions without financial deepening (Figure 9) disappear. This, in turn, further reduces the adoption threshold.

The analysis of the influence of financial deepening on technology choices is only possible when both deposits and credit are available. When the scenarios of credit and deposits are separated, financial deepening only means either that loans are less expensive or that the interest income earned on deposits is higher. The effect of these partial financial regimes under the new levels of interest rates, on the thresholds for adoption and abandonment, is shown in Appendix B. While a more favorable interest rate on deposits increases the adoption thresholds, a lower interest rate on loans decreases the thresholds only slightly.

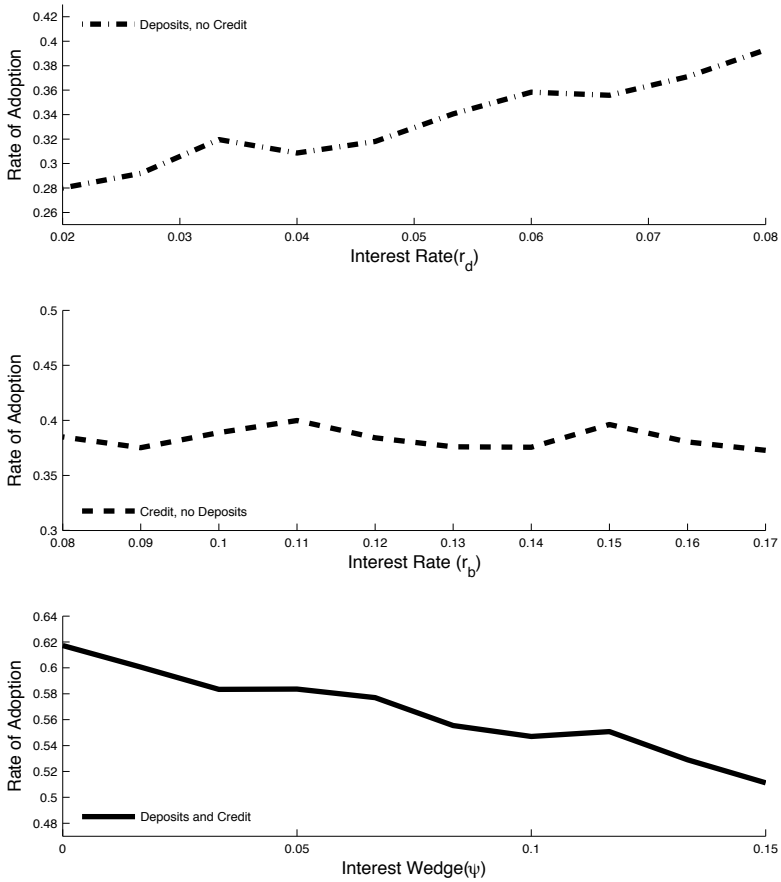
Figure 10: Net Financial Holdings Optimum Policy Function with Equal Interest Rates



The asymmetric effect of interest rates on these thresholds originates in the wealth effect of deposits. A higher adoption wealth threshold for the case with deposit facilities does not, however, necessarily mean that adoption will take longer to occur. The opposite may be true, as the interest income earned becomes higher, which may facilitate reaching the threshold sooner.

The small changes in the adoption thresholds for the case of just credit are reflected in the small variability of adoption rates in the steady state (Figure 11, middle panel). A lower interest rate charged on loans may facilitate adoption, reducing the time to adopt; however, in the steady state, the rates of adoption show a very small variation, between 37 and 39 percent, without a visible pattern.

Figure 11: Interest Rate Effects on the Steady-state Distribution over Technologies



In contrast, a higher interest rate paid on deposits (Figure 11, top panel) raises the steady state rate of adoption from 27 percent ($r_d = 0.02$) to 39 percent ($r_d = 0.08$). Thus, in steady state, sufficiently high interest rates on deposits may allow deposit facilities to outperform the effect of cheaper credit on adoption.

When the benefits of access to credit and to deposits are combined in a scenario of full financial inclusion, the adoption rates are higher than in any other scenario (Figure 11, bottom panel). This high degree of effectiveness of financial inclusion is even larger when there is full financial deepening (e.g., when the wedge tends to zero), since the rate of adoption is 60 percent.

The increments in use rates are not only caused by the effects of the better financial

Table 4: Wealth Interest Rate Effects on Technology Abandonment

Wedge (ψ)	**Deposits**	**Credit**	**Inclusion**
0.15	3.02	3.41	1.65
0.13	2.83	3.28	1.59
0.12	2.62	3.11	1.52
0.08	2.52	3.31	1.60
0.07	2.31	3.14	1.55
0.05	2.07	2.96	1.54
0.03	2.07	3.05	1.58
0.02	1.91	3.13	1.55
0.00	1.74	3.07	1.52

conditions on the adoption side, but also on the abandonment side. Financial instruments allow the farmer to better cope with the risk associated with the advanced technology and, therefore, make it easier to sustain the adoption. Table 4 shows how a lower interest rate wedge reduces the turnover rates between the technologies. This result also confirms that access to deposit facilities permits the farmer to better cope with risk.

5 Conclusions

An important literature has documented the complexities that farmers face in the process of adopting advanced technologies. Because of the potential of these barriers to generate poverty traps and their direct relationship with financial markets, this research focuses on examining the complexities related to the riskiness and size of the lumpy investments associated with the advanced technologies. We then explore how different scenarios of financial inclusion (full financial exclusion, only access to deposits, and only access to credit) may affect the farmer's decision of adopting or abandoning advanced technologies of production. These models add some relevant features of poorly developed financial markets: severe credit rationing (through borrowing limits) and lack of financial deepening (by setting high interest rates on loans and low interest rates on deposits).

Via the numerical approximation of infinite horizon, dynamic, stochastic models, we begin by solving the representative farmer's dynamic decision problem for the three different scenarios of financial inclusion. The state-contingent value functions and the optimal policies of the representative agent allow me to identify regions where, although the financial service is available, the marginal utility of current consumption is so high that the farmer does not demand the deposit facilities available or is not prepared to improve his balance sheet position. Although quite intuitive, the existence of these regions may explain why just the provision of credit or deposit facilities may be fruitless for technology adoption in very low-income settings.

By expanding the model to a large economy where farmers behave as the representative agent does, but who as a result of having experienced distinct production shocks are heterogenous with respect to wealth and choice of technology, we am able to examine the effects of full financial exclusion, just credit and just deposits on technology choices at the aggregate level. Some researchers have studied the links between poverty traps and technology adoption by using models with divisible technologies or technologies of low risk. We take advantage of the dynamic setting to investigate the extent to which models that incorporate technologies of this nature are able to capture poverty traps. The results suggest that, under reasonable assumptions, if the advanced technology requires a low level of a

lumpy investment or represents a low production risk, the majority of farmers will be able to eventually adopt. Thus, poverty traps, understood as a state of persistent poverty, are not quite captured by those models.

Using the baseline parameters, the results verify that scenarios of partial financial inclusion, either deposit facilities or access to credit, bring notably more benefits, in terms of the sustained adoption of the advanced technology, than the scenario of full financial exclusion. Furthermore, while credit is more effective in inducing adoption rates, access to deposits is more effective in preventing the abandonment of the advanced technology. By simulating different borrowing limits, the results suggest that unless the size of the loan is sufficiently large, the provision of deposit facilities would be a superior policy to increase rates of technology adoption.

This paper also explores how the benefits of the two scenarios of partial inclusion are combined in a scenario of full financial inclusion. The farmer's inclusion in the credit and deposit markets increases the adoption rate of the economy, in the steady-state, to 50 percent, as compared to the scenario of full financial exclusion (8 percent), only deposits (27 percent), and only credit (38 percent). The net-saving optimal policy functions point out areas of wealth where, due to the lack of financial deepening (high interest rates charged on loans and low rates paid on deposits), the farmers are not willing to use these financial services. After removing the gap in the interest rates, the results suggest that the effectiveness of financial inclusion in promoting adoption is even greater.

The increments in the adoption rates due to full financial inclusion are not only caused by the better financial conditions (less expensive credit and higher deposit income earnings) but are also due to the fact that these financial instruments allow the farmer to better cope with the risk associated with the advanced technology and, therefore, make it easier to sustain the adoption. When there is only credit, the results indicate that, in the steady-state, adoption rates are insensitive to the level of the interest rates. This implies that, even after the loans are available, the farmers remain credit-constrained and there is an unsatisfied demand for credit that is not addressed because of the credit limits. Only if the credit limits became less constraining, would the demand for credit become sensitive to the interest rates. Thus, the simulations reflect a situation of true non-interest credit rationing. In contrast, when only

deposit facilities are available, the adoption rate is larger and theabandonment rate is lower with higher interest rates paid on financial savings.

This set of results suggests important conditions for the successful implementation of financial policies. The models, however, can be extended in several directions for specific guidance. Analyzing the provision of credit conditioned on adopting the technology, incorporating the farmer's life-cycle, and studying the implications for inequality are only some interesting dimensions. To strengthen the arguments of this study, we are currently working on testing some of its implications using empirical estimations.

References

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Adams, Dale W, Douglas H. Graham, and J. D. Von Pischke (eds.), (1984). Undermining Rural Development with Cheap Credit. Colorado: Westview Press.

Aghion, Philippe and Beatriz Armendariz de Aghion, (2004). "A New Growth Approach to Poverty Alleviation." Manuscript. Harvard University.

Ahlin, Christian, and Neville Jiang, (2008) "Can Micro-credit Bring Development?" Journal of Development Economics 86: 1-21.

Alpizar, Carlos A., (2007). "Risk Coping Strategies and Rural Household Production Efficiency: Quasi-experimental Evidence from El Salvador." Ph.D. Dissertation. Department of Agricultural, Environmental, and Development Economics (The Ohio State University).

Ardeva, Anita, and Elisabeth Rhyne, (2011). Opportunities and Obstacles to Financial Inclusion: Survey Report. Washington, D.C.: Center for Financial Inclusion at ACCION International.

Armendariz, Beatriz and Jonathan Morduch, (2005). The Economics of Microfinance. Cambridge, MA: The MIT Press.

Banerjee, Abhijit and Esther Duflo (2008), "The Experimental Approach to Development Economics". National Bureau of Economic Research Working Papers.

Banerjee, Abhijit, Esther Duflo, Rachel Glennester, and Cynthia Kinnan, (2009). "The Miracle of Microfinance? Evindence from a Randomized Evaluation." MIT.

Banerjee, Abhijit and Esther Duflo (2010), "Giving Credit where Credit is Due". MIT unpublished manuscript.

Beneke de Sanfeliu, Margarita, and Claudio Gonzalez-Vega, (2000). "Dynamics of Rural Household Incomes in El Salvador: 1995-1997 Panel Results." Annual Meeting of the Latin American and Caribbean Economics Association, Rio de Janeiro.

Bhattacharya, Sudipto, Arnoud W. A. Boot and Anjan V. Thakor. (1998). "The Economics of Bank Regulation." Journal of Money, Credit, and Banking, 30 (4), 745-770.

Besley Timothy and Anne Case, (1993). "Modeling Technology Adoption in Developing Coun-

tries" The American Economic Review 83, no. 2: 396-402.

Braverman, Avishay and Jose Luis Guash (1986), "Rural Credit Markets and Institutions in Developing Countries: Lessons for Policy Analysis from Practice and Modern Theory," World Development, Vol. 14, pp. 1253-67.

Bravo-Ureta, B., and A. Pinheiro. (1993). "Efficiency Analysis of Developing Country Agriculture: A Review of the Frontier Function Literature." Agricultural and Resource Economics Review, 22(1): 88-101.

Brune, Lasse, Xavier Gin, Jessica Goldberg, and Dean Yang (2011). "Commitments to Save: a Field Experiment in Rural Malawi." Policy Research Working Paper WPS5748.

Cameron, Lisa A., (1999)."The Importance of Learning in the Adoption of High-Yielding Variety Seeds." American Economic Review 83: 396-402.

Carter, Michael R, and Christopher B Barrett, (2004). "The Economics of Poverty Traps and Persistence Poverty: An Asset-based Approach." BASIS Collaborative Research Support Program.

Chavas, J.P., R. Petrie and M. Roth. (2005). "Farm Household Production Efficiency: Evidence from The Gambia" American Journal of Agricultural Economics, 87(1): 160-179.

Chaves, Rodrigo A. and Claudio Gonzalez-Vega, (1994). "Principles of Regulation and Prudential Supervision and their Relevance for Microenterprise Finance Organizations," in Maria Otero and Elisabeth Rhyne (eds.), The New World of Microenterprise Finance. Building Healthy Financial Institutions for the Poor, West Hartford, Conn.: Kumarian Press, pp. 55-75.

Conley, Timothy G. and Christopher Udry, (2010). "Learning about a New Technology: Pineapple in Ghana." American Economic Review 100, no.1: 35:72.

Croppenstedt, Andre, Mulat Demeke and Meloria M. Meschi, (2003). "Technology Adoption in the Presemce of Constraints: the Case of Fertilizer Demand in Ethiopia" Review of Development Economics 7, no. 1: 58-70.

de Mel, Suresh, David McKenzie, and Christopher Woodruff, (2009). "Are Women More Credit Constrained? Experimental Evidence on Gender and Microenterprise Returns." American Economic Journal: Applied Economics 1, no. 3: 1-32.

de Mel, Suresh, David McKenzie, and Christopher Woodruff, (2008). "Returns to Capital in Mi-

croenterprises: Evidence from a Field Experiment." The Quarterly Journal of Economics 123, no. 4: 1329-1372.

De Meza, David and David C. Webb, (2006). "The Near Impossibility of Credit Rationing." FMG Discussion Papers. Financial Markest Group.

Dercon, Angus (1992). "Household Saving in LDCs: Credit Markets, Insurance and Welfare". The Scandinavian Journal of Economics 94, no. 2: 253:273.

Dewatripont, Mathias and Jean Tirole. (1999). The Prudential Regulation of Banks Cambridge, MA: The MIT Press.

Karlan, Dean, and Jonathan Zinman, (2009). "Expanding Microenterprise Credit Access: Using Randomized Supply Decisions to Estimate the Impacts in Manila." Innovations for Poverty Action.

Dercon, Stefan, (1998). "Wealth, Risk and Activity Choice: Cattle in Western Tanzania." Journal of Development Economics 55, 1:52.

Dercon, Stefan, and Luc Christiaensen, (2011). "Consumption Risk, Technology Adoption and Poverty Traps: Evidence from Ethiopia." Journal of Development Economics 96: 159-173.

Doss, Cheryl R., (2006). "Analyzing Technology Adoption using Microstudies: Limitations, Challenges, and Opportunities of Improvement." Agricultural Economics 34: 207-2019.

Duflo, Esther, Michael Kremer, and Jonathan Robinson, (2006). "Why Don't Farmers Use Fertilizers: Evidence from Field Experiments in Western Kenya." Working Paper.

Duflo, Esther, Michael Kremer, and Jonathan Robinson, (2006). "Psychology and Development: Theory and Experimental Evidence." American Economic Review 98, no.2: 482:488.

Duflo, Esther, Rachel Glennerster, and Michael Kremer (2008), "Using Randomization in Development Economics Research: A Tollkit," in T.P Schultz and J. Strauss (eds.), Handbook of Development Economics, pp. 3895-3962, Amsterdam: Elsevier.

Dupas, Pascaline and Jonathan Robinson, (2012). "Savings Constraints and Microenterprise Development: Evidence from a Field Experiment in Kenya." Working Paper.

Fafchamps, Marcel, and John Pender, (1997). "Precautionary Saving, Credit Constraints, and Irreversible Investment: Theory and Evidence fron Semi-Arid India." Journal of Business and Economic Statistics (International Food Reasearch Institute) 15, no. 2: 180-194.

Fafchamps, Marcel, Christopher Udry, and Katherine Czukas, (1998). "Drought and Savings in West Africa: Are Livestock a Buffer Stock?" Journal of Development Economics 55, no. 2: 273-305.

Feder, Gershon, Richard E. Just and David Zilberman, (1985). "Adoption of Agricultural Innovations in Developing Countries: A Survey" Economic Development and Cultural Change 33, no. 2: 255-298.

Foster, Andrew D. and Mark R. Rosenzweig, (1995). "Learning by Doing and Learning from Others: Human Capital and Technical Change in Agriculture." Journal of Political Economy 103, no. 6: 1176-1209.

Giné, Xavier, and Dean Yang, (2009). "Insurance, Credit, and Technology Adoption: Field Experimental Evidence from Malawi." Journal of Development Economics 89: 1-11.

Gomez-Soto, Franz M, (2007). "Deposit Facilities and Consumption Smoothing: A Dynamic Stochastic Model of Precautionary Wealth Choices for a Credit-Constrained Rural Household." Ph.D. Dissertation. Department of Agricultural, Environmental, and Development Economics (The Ohio State University).

Gonzalez-Vega, Claudio., (1976) "On the Iron Law of Interest Rate Restrictions: Agricultural Credit Policies in Costa Rica and in other Less Developed Countries." Ph.D. Dissertation. Stanford, California: Stanford University.

Gonzalez-Vega, Claudio, (1977). "Interest Rate Restrictions and Income Distribution." American Journal of Agricultural Economics LIX, no. 5: 973-976.

Claudio Gonzalez-Vega (1980), "Interest Rate Restrictions and the Socially Optimum Allocation of Credit." Savings and Development. Volume IV. No. 1. (January), pp. 5 28.

Gonzalez-Vega, Claudio, (2003). "Deepening Rural Financial Markets: Macroeconomic, Policy and Political Dimensions." International Conference on Paving the Way Forward for Rural Finance. Washington, D.C.: WOCCU and USAID.

Gonzalez-Vega, Claudio, (2011). "Microfinance, Systemic Risk, and the Rural Poor." Global Microcredit Summit.

Jacoby, Hanan G. and Emmanuel Skoufias, (1998). "Testing Theories of Consumption Behavior Using Information on Agregate Shocks: Income Seasonality and Rainfall in Rural India." American Journal of Agricultural Economics 80, no. 1: 1-14.

Jalan, Jyotsna, and Martin Ravallion, (2001). "Behavioral Responses to Risk in Rural China." Journal of Development Economics 66, no. 1: 23-49.

Karlan, Dean, and Jonathan Zinman, (2009). "Expanding Microenterprise Credit Access: Using Randomized Supply Decisions to Estimate the Impacts in Manila." Innovations for Poverty Action.

Karlan, Dean, Ed Kutsoati, Margaret McMillan, and Chris Udry, (2010). "Crop Price Indemnified Loans for Farmers: A Pilot Experiment in Rural Ghana." Working Paper.

Kazianga, Harounan, and Christopher Udry, (2006). "Consumption Smoothing? Livestock, Insurance and Drought in Rural Bukina Faso." Journal of Development Economics 79, no. 2: 413-446.

Keeton, William, (1979). Equilibrium Credit Rationing. New York: Garland Press.

Kotchar, Anjini, (1999). "Smoothing Consumption by Smoothing Income: Hours-of-work Responses to Idiosincratyc Agricultural Shocks in Rural India." The Review of Economic and Statistics 81, no. 1: 50-61.

Levine, Ross, (1997). "Financial Development and Economic Growth: Views and Agenda." Journal of Economic Literature 35, no. 2: 688-726.

Lloyd-Ellis, Huw, and Dan Bernhardt, (2000). "Enterprise, Inequality and Economic Development." Review of Economic Studies 67, no. 1: 147-168.

Maldonado, Jorge H, and Claudio Gonzalez-Vega, (2008). "Impact of Micro?nance on Schooling: Evidence from Poor Rural Households in Bolivia." World Development 36, no. 11: 2440-2455.

McKenzie, David J. and Christopher Woodruff, (2006). "Do Entry Costs Provide Empirical Basis for Poverty Traps? Evidence from Mexican Microenterprises." Economic Development and Cultural Change 55: 3-42.

McKinnon, Ronald I, (1973). Money and Capital In Economic Development. Washington, D.C.: The Brooking Institution.

McKinnon, Ronald I. (1989), "Macroeconomic Instability and Moral Hazard in Banking in a Liberalizing Economy," in Philip L. Brock, Michael B. Conolly and Claudio Gonzalez-Vega (eds.) Latin American Debt and Adjustment. External Shocks and Macroeconomic Policies, New York: Praeger.

Miranda, Mario J, and Paul L Fackler, (2002). Applied Computational Economics and Finance. Cambridge, Massachusetts: The MIT Press.

Moser, Christine M. and Christopher B. Barret, (2003). "The complex Dynamics of Smallholder Technology Adoption: The Case of SRI in Madagascar." Working Paper.

Morduch, Jonathan, (1995). "Income Smoothing and Consumption Smoothing." Journal of Economic Perspectives 9, no. 3: 103-114.

Ouma, James O., Festus M Murithi, Wilfred Mwangi, Hugo Verkuijl, Macharia Gethi, Hugo De Groote, (2002). "Adoption of Maize Seed and Fertilizer Technologies in Embu District, Kenya." International Maize and Wheat Improvement Center (CIMMYT), Mexico, D.F.

Parker, Simon C., (2000) "Saving to Overcome Borrowing Constraints: Implications for Small Business Entry and Exit." Small Business Econmics 15: 223-232.

Robinson, Marguerite S. (1998), "Microfinance: The Paradigm Shift from Credit Delivery to Sustainable Financial Intermediation," in Mwangi S. Kimenyi, Robert C. Wieland, and J.D. Von Pischke (eds.), Strategic Issues in Microfinance, Aldershot, England: Ashgate.

Salasya, B.D.S., W. Mwangi, H. Verkuijl, M.A. Odeondo, and J.O. Odenya, (1998). "Adoption of Seed and Fertilizer Packages and the Role of Credit in Smallholder Maize Production in Kamakega and Vihiga Districs, Kenya" International Maize and Wheat Improvement Center (CIMMYT), Mexico, D.F.

Rosenzweig, Mark R. and Kenneth I. Wolpin, (1993). "Credit Market Constraints, Consumption smoothing, and Land Accumulation of Durable Production Assets in Low-Income Countries: Investments in Bullocks in India." Journal of Political Economy 101, no.2: 223-244.

Singh, Inderjit, Lyn Squire, and John Strauss, (1986). "A Survey of Agricultural Household Models: Recent Findings and Policy Implications." World of Agricultural Household Models: Recent Findings and Policy Implications. World Bank Economic Review 1 149-179.

Shaw, Edward S, (1973). Financial Deepening in Economic Development. New York, D.C.: Oxford University Press.

Sherlund, S.M., C.B. Barrett, and A.A. Adesina. (2002). "Smallholder Technical Efficiency Controlling for Environmental Production Conditions." Journal of Development Economics, 69(1): 85-101.

Suri, Tavneet, (2011). "Selection and Comparative Advantage in Technology Adoption." Econometrica 79, no. 1: 159-209.

Sunding, David and David Zilberman, (2000). "Research and Technology Adoption in a Changing Agricultural Sector." The Handbook of Agricultural Economics.

Stiglitz, Joseph E, and Andrew Weiss, (1981). "Credit Rationing in Markets with Imperfect Information." The American Economic Review 71, no. 3: 393-410.

Udry, Christopher, and Santosh Anagol, (2006). "The Return to Capital in Ghana." American Economic Review 96, no. 2: 388-393.

Von Pischke, J.D., Dale W Adams, and Gordon Donald, eds. (1983), Rural FinancialMarkets in Developing Countries. Their Use and Abuse, Baltimore: The Johns Hopkins University Press.

Yaron, Jacob, McDonald P. Benjamin, and Stephanie Charitonenko (1998), "Promoting Efficient Rural Financial Intermediation," The World Bank Research Observer, Vol. 13, No. 2, August, pp. 147-170.

Zimmerman, Frederick J, and Michael R Carter, (2003). "Asset Smoothing, Consumption Smoothing and the Reproduction of Inequality under Risk and Subsistence Constraints." Journal of Development Economics 71: 233-260.

Appendix A

Figure 12: Residuals Functions of the Model with Financial Exclusion

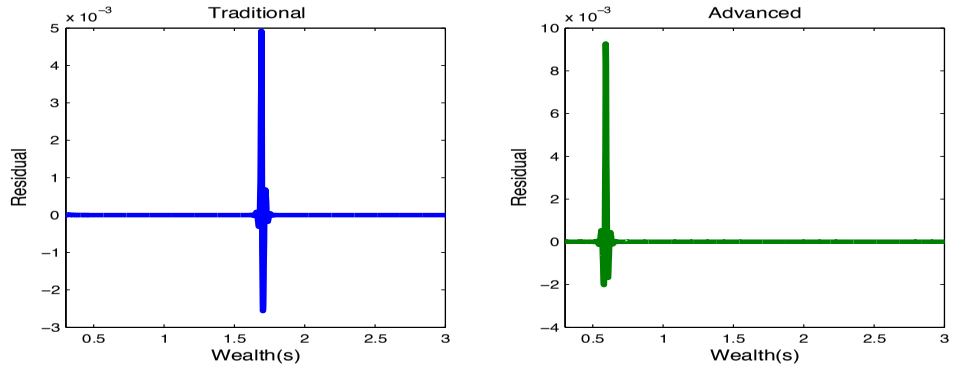


Figure 13: Residuals Functions of the Model with Deposits

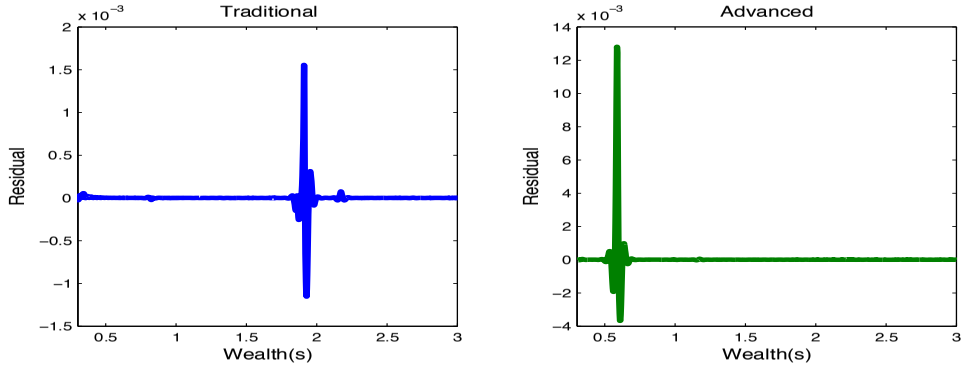


Figure 14: Residuals Functions of the Model with Credit

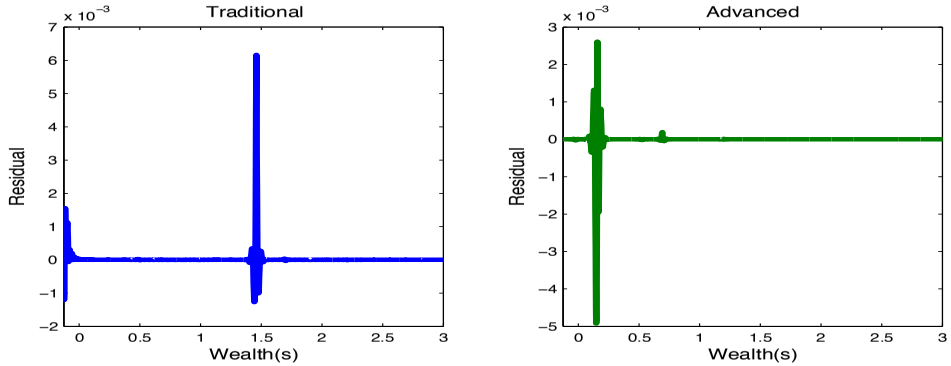
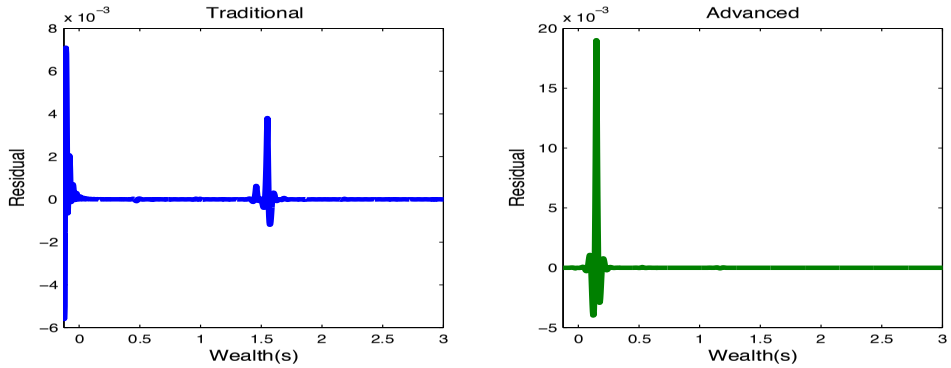


Figure 15: Residuals Functions of the Model with Financial Inclusion



Appendix B

Figure 16: Parametric Analysis

			Exclusion	Deposits	Credit	Inclusion
Discount Factor (δ)	Thresholds	Low (0.83)	1.75	2.10	1.57	1.85
			0.63	0.64	0.22	0.21
		High (0.90)	1.56	1.67	1.30	1.39
			0.49	0.47	0.06	0.05
	Adoption Rates	Low	0.04	0.05	0.15	0.12
		High	0.48	0.98	0.94	0.99
	Abandonment	Low	18.35	6.31	6.49	3.31
		High	2.78	0.32	0.58	0.99
Risk Aversion (α)	Thresholds	Low (1.5)	1.71	1.88	1.50	1.62
			0.54	0.52	0.09	0.08
		High (2.5)	1.68	1.94	1.48	1.70
			0.62	0.63	0.22	0.21
	Adoption Rates	Low	0.13	0.33	0.54	0.64
		High	0.07	0.28	0.31	0.47
	Abandonment	Low	6.15	1.46	1.32	0.72
		High	16.26	4.05	5.29	0.32
Reversibility (ρ)	Thresholds	Low (0.25)	1.72	1.96	1.50	1.69
			0.51	0.49	0.04	0.03
		High (0.75)	1.68	1.88	1.46	1.60
			0.64	0.69	0.29	0.29
	Adoption Rates	Low	0.16	0.50	0.74	0.77
		High	0.06	0.13	0.16	0.26
	Abandonment	Low	4.20	0.48	0.39	0.20
		High	20.09	11.25	14.86	8.58

Figure 17: Effect of the Borrowing Limit on Thresholds of Wealth for Adoption and Abandonment

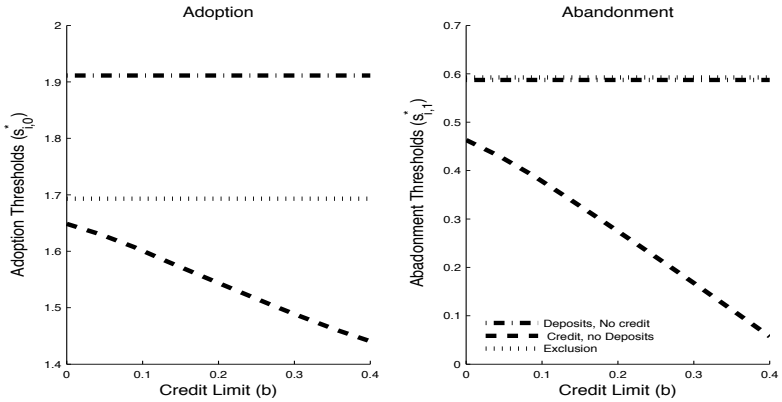


Figure 18: Financial Deepening Effects on Thresholds of Wealth for Adoption and Disadoption