Premium Benefits? A Heterogeneous Agent Model of Credit-Linked Index Insurance and Farm Technology Adoption

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Abstract

Lack of protection from downside risk has been posited as one explanation for sluggish technology uptake among subsistence agricultural households in the developing world. Access to credit and insurance is thought to be a stimulant to technology adoption where new methods are riskier but higher yielding on average, or, in the alternative, require sunk costs of investment that can be significant for households that already consume very little when harvests are poor. Despite recent efforts to pilot index-based insurance to smallholder farmers where no formal insurance was previously available, demand for individual-level contracts has been unexceptional at best, even when premiums are highly subsidized. On the flip side, the effect of index insurance on credit supply is ambiguous: if clients are insured against potential losses, theory suggests that credit supply should increase, as banks face lower probabilities of systemic default; however, due in part to the nature of basis risk that is inherent in index-based contracts, there are cases in which mandatory index insurance that indemnifies the policyholder directly can lead to decreased internal rates of return for lending institutions. In this paper, we employ a dynamic, stochastic, heterogeneous agent model where farm households have access to contingent credit or credit-linked insurance, and may also make dichotomous choices regarding technology and loan repayment in each period. The approach we take is novel in that insurance is modeled as a meso-level product, where the bank is first indemnified before any payouts are distributed to its borrowing clients. Thus, the model we put forward takes into account both supply- and demand-side concerns, and shows the possibilities of a trickle-down effect when index insurance contracts are sold not to individual households, but instead to risk aggregators for whom basis risk is lower. Results show that insurance can have a positive effect on technology uptake, while letting the lender lay first claim on indemnities lowers default rates.

1 Introduction

An extensive risk-coping literature is omnipresent in development economics research, with work focused around the question of whether or not poor households can informally manage risk in the absence of formal financial tools. There has been evidence of informal risk sharing through reciprocal lending within social networks, resulting in fairly smooth household consumption profiles when controlling for village-level consumption patterns (*see*, e.g., the seminal paper by Townsend (1994), where the complete insurance hypothesis is statistically rejected, but where household consumption is found to comove with village average consumption in Indian data).[†] However, these sorts of risk sharing arrangements, while effective at managing idiosyncratic risk, may be insufficient when a systemic shock lowers the income of all households in a region.

The failure of households to fully insure can result in severe repercussions. In this paper, we focus on the tradeoff between uncertainty of income and higher returns to investment that can cause poor agricultural households to remain in persistent poverty. While interlinked index insurance is only one policy option that has the potential to help these households emerge from a dynamic poverty trap, we employ such a mechanism because it is likely feasible given the stylized facts of agrarian economies in low-income countries: risk-averse households using uninsured credit for consumption rather than investment, credit constraints stemming from systemic risk exposure, a lack of traditional insurance due to high transactions costs, and informal insurance that smoothes consumption fairly well in the face of idiosyncratic shocks.

[†] Note that informal risk sharing does not necessarily protect households against even idiosyncratic income shocks. Jalan and Ravallion (1999), for example, find evidence of differential (but never full) insurance among a panel of Chinese households; the poorest decile is found to transfer 40 percent of an idiosyncratic income shock to current consumption, compared with a pass-through rate of only 10 percent for the richest third of households.

While the richness of the model presented provides the potential to conduct a number of policy analyses, the motivation of this paper is to address select research questions that will offer inferences on the formulation of development policy that aims to alleviate rural poverty. Namely, this paper will focus on three principal problems:

1. Does the availability of insurance induce subsistence farming households to adopt high-technology methods that provide higher incomes on average?
2. Under what conditions does high-technology adoption result in welfare gains relative to the employment of traditional technology?
3. What types of credit and insurance schemes reduce the incidence of default among rural borrowers, so that financial institutions are able to continue lending, expand lending, or lower interest rates on borrowing?

Similar to the findings of Janzen, Carter and Ikegami (2012), where access to insurance reduces households' vulnerability to a fall into poverty, as well as increases the likelihood of reaching a high-level equilibrium, we find that, under certain conditions, households with access to interlinked credit-insurance contracts are more likely to employ high-technology farming practices. In turn, these high-technology households have higher long-run consumption rates than those of traditional technology households. Finally, although technology adoption is the highest where credit and insurance are separately available to rural households as opposed to being offered as a bundled product, this policy is also the one in which loan default rates are the highest. It is, therefore, important to approach the proceeding policy analysis in a manner that can reconcile the seemingly divergent goals of high technology adoption and low rates of loan default.

A notable difference in the approach in this paper is the way in which indemnity payments are disbursed. In a recent article, Miranda and Gonzalez-Vega (2011) find that mandatory, unsubsidized index insurance for individual farmers can diminish a bank's internal rate of return; this is due to the perverse effects of premium burdens that disincentivize borrowers from repaying loans. However, they do not consider the effects of contingent credit or credit-linked insurance. For the purposes of this paper, contingent credit refers to a loan that is coupled with an index insurance contract that covers the value of the loan upon maturity, the premium for which is deducted from the loan value before it is disbursed. Credit-linked insurance is similar to contingent credit, but the index insurance contract in this case covers the entire portion of a borrower's agricultural income that is determined by systemic factors, not solely the value of the loan. Thus, technology adoption is expected to be greater under the latter contract type.

Under both contracts, any indemnity triggered is first delivered to the bank; the bank then passes the indemnity on to the borrower, net any unpaid portion of his outstanding loan debt. Thus, the flow of indemnity payments prevents one type of strategic default that can occur if indemnities are paid directly to individual farmers. For purposes of comparison, we also run a model where, similar to the principal model, insurance is mandatory for those who wish to borrow, but where the initial claimant is the borrower himself and not the lending institution. This paper thus contributes to the existing literature by laying out a dynamic model that incorporates the benefits of a meso-level index insurance product, but does so with a greater emphasis on demand-side considerations.[‡]

[‡] Chantarat, Mude, Barrett and Carter (2012), for example, examine demand-driven design of livestock index insurance, but market the product at an individual level. While they look at implications for the risk exposure of the insurer, implications for credit performance of insured borrowers are not explored.

The rest of the paper is organized as follows: Section 2 provides a review of the relevant literature, including that on informal risk coping, technology adoption, index insurance, and spillover effects of formal insurance, to provide a background and create a practical context for the model; Section 3 introduces two representative agent models that differ only in the flow of indemnity payments, as discussed above, and subsequently extends the representative agent model to a heterogeneous agent model; Section 4 presents the numerical results of simulations of the heterogeneous agent models under base parameter assumptions; Section 5 offers a sensitivity analysis of the results; Section 6 concludes.

2 Literature Review

2.1 Informal Risk Coping Mechanisms in the Absence of Formal Insurance

In the absence of access to affordable insurance, rural households in developing countries attempt to protect themselves from risk using informal, non-market mechanisms. Many empirical studies have found evidence of non-market risk sharing within low-income communities (Fafchamps 1992; Ligon, Thomas and Worrall 2002; Foster and Rosenzweig 2001; Coate and Ravallion 1993). However, most of this risk sharing applies only to idiosyncratic risk, and generally provides very limited protection against systematic shocks such as droughts and floods (Sawada 2007).

Means of dealing with agricultural risk in the absence of formal insurance markets are varied. Fafchamps, Udry, and Czukas (1998) find that holding farm assets such as livestock offers a very poor hedge against widespread weather shocks, since, during such events, many farmers simultaneously attempt to liquidate their assets, depressing prices in the process. Kazianga and

Udry (2006) find evidence of self insurance through the use of grain stocks in rural Burkina Faso. In this case, an extremely severe drought resulted in a failure of households to maintain their habit consumption levels. Kochar (1999) finds that agricultural households in India shift from working on the farm to becoming formally employed outside of the home (in nonfarm labor or, if the shock is idiosyncratic, on another household's farm). However, this means of risk coping works well only if labor markets function efficiently, and generally does not protect against fluctuation in consumption resulting from systemic shocks.

Many risk-coping mechanisms employed by agricultural households come at the sacrifice of profitability, a tradeoff that is clearly explained by classical portfolio theory (Heady 1952). Risk presents an impediment to the adoption of more profitable agricultural production practices in developing countries, such as the adoption of high-yield seed, accumulation of herds, or expansion of farm size (Mude, Chantarat, Barrett, Carter, Ikegami, and McPeak 2009). As such, farmers in developing countries on average make lower incomes than would be possible if they had access to formal insurance to protect their income and investments. The lifetime potential income loss that comes from risk aversion and the accompanying conservatism of poor rural households has been scrutinized in many empirical studies, some of which are outlined below.

Rosenzweig and Wolpin (1993) stress that, with incomplete financial markets for risk management, households cannot separate production and consumption decisions and thus are forced to make the tradeoff between current and future consumption by altering production choices. Using data from rural India, the authors find that households tend to sell bullocks — a productive asset used in planting and harvesting crops — when they realize low income in a

given year. Farmers not only sacrifice future income by selling off durable assets, but also find themselves selling their livestock at depressed prices when a systemic shock occurs due to the flooding of the market.

Similarly, Clarke and Dercon (2009) examine the effect of shocks on a panel of Ethiopian households between 1999 and 2004. They find that while consumption goes unsmoothed during severe droughts, households engage in income smoothing, as evidenced by lower-than-optimal fertilizer use. Thus, when farm households cannot insure, they may be unwilling to purchase inputs or employ technology that would, on average, increase agricultural income. This is especially the case if a household is near subsistence level and attempts to minimize downside risk to avoid a fall into poverty after an adverse shock.

Catastrophic disasters, even when they are short in duration, can also have serious ramifications for long-term income growth, agricultural productivity, asset accumulation and even child development (Chantarat, Mude, Barrett and Turvey 2007). Just one shock can greatly affect the future potential earnings of a hard-hit household. In Ethiopia, for example, a study finds that families more severely impacted by a drought-induced famine in 1984 and 1985 were 16 percent poorer than those less affected, even ten years later (Bryla 2009). In Zimbabwe, a 1994-95 drought is associated with a loss of 15 to 20 percent of growth velocity for children under two, which likely resulted in a permanent loss of stature, schooling and earnings (Hoddinott 2006). Thus, informal risk-coping mechanisms may not be enough to bring rural households out of poverty.

Zimmerman and Carter (2003) find similar results when examining asset accumulation patterns and portfolio choice through the use of a stochastic, dynamic programming model that incorporates endogenous asset price risk. Farmers in a stylized village representative of Burkina Faso must choose between two assets available for investment: a risk-free and low-return asset (e.g., grain) and a risky, high-return asset (e.g., land or livestock). Results show a divergence in portfolio strategies between rich and poor households, where the wealthy engage in high return activities and smooth consumption by drawing down assets after an income shock. The poor, on the other hand, pursue a defensive portfolio strategy, and tend to smooth income and assets while conceding more variable consumption to maintain a base level of assets in bad years. Interestingly, while the poor face higher maximum attainable returns to the productive asset than the rich (due to a decreasing returns assumption), the mean rate of return is lower for the poor than for the rich when the defensive strategy is employed. Carter and Lybbert (2012) corroborate these asset dynamics results using panel data from Burkina Faso, and, analyzing data on Kenyan herders, Lybbert and McPeak (2012) also find supporting empirical evidence of asset smoothing in response to a dynamic asset threshold.

Little empirical work exists to estimate the magnitude of inefficiency losses from household income-generating choices in the absence of complete insurance markets. This may be due to the fact that data limitations impede the estimation of the causal effect of uninsured risk on production. For causal impacts, researchers need a quantifiable measure of exposure to risk, a source of identification that differentiates exposure to risk among individuals or firms, and a way to limit omitted variable and unobserved heterogeneity biases (Roberts, O'Donoghue and Key 2007). Unobserved heterogeneity presents itself in observational studies, as certain risk types

(not distinguishable by the researcher) may self-select into insurance, while also engaging in other risk-mitigating strategies because they alone know their level of risk. If selection bias is unaccounted for, it may be concluded that a relationship exists between insurance and income generated from farming activities when in reality the correlation could simply be spurious (Cai, Chen, Fang, and Zho 2009). The task of measuring welfare benefits from gaining access to insurance is thus rather daunting, although not impossible given the right data.

However, risk mitigation strategies are often observed in developing countries where agricultural households have no formal insurance. For example, in examining cropping patterns in a region where credit and insurance markets were absent, Larson and Plessmann (2009) find Filipino farmers choose to forego efficient production by choosing to over diversify rather than specialize in rice production. Notable differences between the insured and the uninsured have also been observed in developing countries. In an empirical study of sow insurance in rural China, Cai, Chen, Fang, and Zho (2009) make the noteworthy qualification between full and efficient insurance. Although household consumption may not fluctuate (conditional on village-level aggregate consumption) with changes in income, this test of full insurance is not necessarily one of efficient insurance. The authors find evidence that more sows are raised when households have access to insurance. This reveals that ex-ante income smoothing is a problem among study participants where no insurance products are available. Much like the case of bullocks in India, Chinese farmers are not investing optimally in sows when insurance is unavailable.

2.2 The Role of Insurance in Technological Adoption

The availability of formal insurance may induce poor, rural households to make productive investments they would not have made had they only had access to informal risk-coping

mechanisms. This is especially the case when insurance is paired with access to other types of finance. For example, Carter, Cheng and Sarris (2011) scrutinize household-level demand for technology and finance (credit and insurance) under three scenarios: (i) no insurance; (ii) stand-alone index insurance; and (iii) interlinked credit-index insurance contracts. The authors find differential effects on demand given the level of collateral held by the household. While insurance-only regimes can markedly increase demand for both technology and financial products among high-collateral households, those with minimal levels of collateral actually display lower demand for technology than under the baseline of no insurance when insurance-only contracts are in place. On the other hand, interlinked contracts increase demand for technology among both low- and high-collateral households.

As discussed in the previous section, uninsured risk at least partially accounts for deficiencies in technology uptake among low-income households. Rosenzweig and Binswanger (1993), using ICRISAT Indian village panel data, reject the hypothesis that agricultural investment composition reflects technical-scale economies, and find support for the hypothesis that asset portfolio choice is highly influenced by farmers' risk aversion and wealth, and by the variability of the weather they face. More importantly, the trade-off between profit variability and average returns is large, and the loss of efficiency associated with risk-coping strategies is higher among low-income households; the existence of uninsured weather risk thus results in increased income inequality. Specifically, farmers are found to reduce the responsiveness of their portfolio returns to weather when weather becomes more variable, but this response attenuates with increasing wealth. While survey households below the 80th percentile in wealth display increases in profit variability that are less than proportional to increases in rainfall variability, the top 20th

percentile appears to fully absorb all rainfall-induced profit risk. In addition, the costs of decreased portfolio risk are disproportionately borne by the lower income groups, as a one-standard-deviation increase in the monsoon onset date coefficient of variation lowers average profits by 4.5 percent (and by 15 percent at the median); profits for farmers in the bottom quartile, in comparison, are found to decrease by 35 percent. Finally, despite these results, the reduced sensitivity of wealthier farmers' profits to rainfall risk does not suggest that these farmers have higher profits per unit of wealth than smaller farmers in an area with high rainfall risk. In fact, the opposite is true, although profit rates fall considerably faster for lower income farmers as rainfall variability increases.

Other determinants of technology adoption seem to serve an insurance purpose even where there are no formal markets for risk management. Where consumption credit is available to agrarian households, for example, it can take on the role of an insurance contract and hence influence risk behavior and production decisions (e.g., technological innovation and investment levels) of farmers (Eswaran and Kotwal 1989). For example, Udry (1990) finds loans among kinship groups or village members in rural Nigeria serve as de facto risk pooling arrangements, whereby the repayment structure is conditional upon production and consumption shocks faced by both the borrower and the lender.

2.3 Index-Based Insurance

Almost twenty years ago, Gautam, Hazell and Alderman (1994) studied risk-coping strategies in India and found that there exists major latent demand for formal insurance products, as households cannot spread risk effectively at the local level when affected by a systemic shock. Even more importantly, the authors were among the first to suggest the use of a rainfall index-

based insurance product as a means to reduce costs stemming from moral hazard. Their novel approach of charging the same premium and making the same indemnity to all policyholders within a given proximity to the same weather station is the very methodology still being used today in many agricultural insurance pilots.

Index insurance products pay out when the realized value of an underlying index either exceeds (e.g., in the case of flood insurance) or falls below (e.g., for drought insurance) a given threshold. The index must be exogenous to the policyholder but should also be significantly correlated with the policyholder's actual losses (Barnett, Barrett and Skees 2008). That a policyholder cannot affect the realization of the index is the feature of index-based contracts that does away with moral hazard; because actual losses are not indemnified, households are incentivized to minimize farm losses – even when they are weather-related.

In addition, index-based products are unique in that, unlike traditional agricultural insurance, all buyers of a particular policy in a given year face the same degree of risk. As the payouts are completely determined by an independent index – not by actual farm outcomes, which may be influenced by an individual's risk behavior or skill in agricultural management – insurers do not face the same problems with adverse selection that plague policies whose indemnities are based off of actual losses. These characteristics of index insurance contracts lower the risk load on charged premiums, as well as reduce monitoring costs to the insurer. Also, transactions costs associated with claims verification are eliminated, which can further reduce premiums faced by farm households.

Much work has gone into the optimal design of index insurance contracts. In a seminal paper, Miranda (1991) formally shows that area-yield crop insurance contracts (i.e., contracts where the relevant index is based on aggregate yield measures) can reduce risk for farmers as long as individual farm yields meet a certain, "critical" degree of sensitivity to the systemic factors that affect average (e.g., county-level) yields. This measure of sensitivity depends on the contract's trigger, defined as the yield level at which farmers begin to receive indemnities. In addition, by varying the coverage farmers can select on insurance contracts, it is likely the case that coverage in excess of 100 percent is optimal for most producers (although it should be noted that some authors, e.g., Skees (1997), have suggested that an upper bound be placed on overcoverage due to political constraints).

While area-yield insurance can be optimally designed in theory, in practice such programs face several obstacles. In an attempt to address empirical issues related the implementation of area-yield index insurance contracts, Carter, Galarza and Boucher (2007) discuss an insurance pilot project for cotton farmers in Peru. Because the basis risk associated with area-yield index insurance is lower than that of contracts based on weather or irrigation water supply indices, the authors estimate that farmers' willingness to pay for area-yield insurance is twice as high as willingness to pay for a contract based on a water flow index. However, important challenges remain:

(i) It is difficult to obtain the quality time series yield data necessary for rating insurance and determining payout structures;

(ii) Farmers are, in general, unfamiliar with insurance (particularly index-based products), and thus creating effective demand for the product may be a cumbersome task;

(iii) If small- and medium-scale producers are target clients, a cost-effective delivery channel must be established; and

(iv) Because there are parameter uncertainties in development and initial implementation stages of area yield programs, insurance companies need incentives to bear the risk associated with this ambiguity.

While the authors are speaking in the context of area-yield-based contracts, much of the difficulties they cite are common to insurance programs based on alternative index types, such as those measuring rainfall or vegetation.

There have been considerable demand-side complications in pilot programs offering voluntary contracts to individuals. One notable failure is that of a World Bank pilot in Ethiopia. In 2006, a stand-alone policy was developed and distributed by a state-owned insurance company. Only thirty farmers purchased insurance policies, with the shortcoming in sales attributed to the lack of an effective distributing agent who could reach and educate potential client farmers; no banks with existing clients would agree to be distributors because loans for fertilizer were guaranteed by the government, and thus there was no incentive to enter the insurance business (Mosley 2009). On the other hand, the sow insurance pilot in China had higher uptake compared to other insurance programs, with 78 percent of sows insured in the aggregate. However, one must take into account that even this level of participation seems somewhat low given that insurance is

heavily subsidized, with central and local governments covering 80 percent of a farmer's premium (Cai, Chen, Fang, and Zho 2009).

Several explanations for this low uptake have been proposed in the literature. First, community education is an important prerequisite for the informed purchase of policies by consumers, in particular with respect to the inherent basis risk associated with these policies (Barnett and Mahul 2007). Education about insurance and risk is invaluable when it comes to generating demand for a new and unfamiliar product.

Along these lines, the insurance provider may also be unfamiliar to potential clients. Once policies have been sold, if indemnities are triggered and payouts are made, the trustworthiness of an insurer becomes clear; this was the case for the sow insurance program, where an ice and snow storm of unprecedented severity hit southern and southwestern China in early 2008 (Cai, Chen, Fang, and Zho 2009). Following government instructions, the insurance company quickly settled claims, solidifying its credibility with policyholders and the uninsured alike. However, at crucial startup periods where households have no knowledge upon which to base their confidence in a potential investment in an insurance policy, a preconceived notion of integrity of the insurer is extremely advantageous for increasing demand.

Second, the design of index insurance programs may not be suitable for potential clients' needs. An obvious issue is that the payment of upfront premiums could be difficult or impossible for households with liquidity constraints. For example, a 2006 survey of households in Andhra Pradesh finds that 80 percent of respondents cite insufficient funds as the most important reason

for remaining uninsured (Gine, Menand, Townsend, and Vickery 2010). Thus, competing ex ante uses for funds (e.g., for fertilizer or inputs) may prevent households from purchasing insurance, even if they have a high willingness to pay for the product.

Some authors have suggested subsidizing premiums, or, in the alternative, offering insurance contracts on credit so a household would be able to spread out its premium payments (Clarke and Dercon 2009). However, households living near subsistence level consumption may find their budget constraints too restrictive for the purchase of insurance, even if they had means of dealing with the aforementioned liquidity problem. For example, Rosenzweig and Wolpin (1993), when simulating the effects of policy options on life-cycle consumption, find that offering actuarially fair weather insurance results in less variable consumption – but average consumption is found to be lower due to monthly costs of the insurance premium. More importantly, the simulations also reveal that households continue to underinvest in productive assets even when weather insurance is subsidized.[§] The lack of demand even for fair insurance may be due to the high cost of premiums relative to what households would pay for alternative risk-coping mechanisms, especially when index insurance does not cover risk that is unrelated to the weather variable measured by the index.

Other arguments have been made in support of subsidies related to costs incurred in the planning and marketing stages of index insurance programs, particularly for assistance with client education and the maintenance and buildup of meteorological infrastructure. Significant benefits of index insurance are reaped by those who are not actual policyholders. Not only is poverty

[§] Note, however, that the authors assume the existence of credit market constraints that do not improve with access to insurance; in addition, the consumption floor they include in their model effectively acts as a substitute for insurance, and may represent farmers' access to informal insurance through transfers.

alleviation and inequality reduction a public good that helps entire communities, the provision of insurance to the poor stabilizes income and cuts default or delinquency costs to microfinance institutions (MFIs), protects human capital in the face of income shocks (e.g., insured households can continue to send their children to school), and protects social capital by preventing the breakup of community and family groups when one member has unpaid debts (Mosley 2009).

Additional policy recommendations on how to tackle the sluggish farm-level demand for index insurance have arisen from recent research. Mandatory credit-insurance bundling has been proposed where the premium payment is implicit, reflected in higher interest rates on loans. However, such policies may reap results that seem counterintuitive. For example, in an RCT in Malawi, farmers' demand for credit is found to *decrease* when loans are bundled with a rainfall insurance contract, even though there is considerable risk of income loss due to drought (Gine and Yang 2009). The reduced demand for credit when insurance is required hypothesized to be due to the fact that implicit insurance already exists in the form of a limited liability clause in the loan agreement.

Finally, even with well-designed contracts and an informed client base, offering farm-level index insurance contracts may be infeasible due to idiosyncratic risk faced by households, which increases basis risk inherent in index insurance coverage. Barnett and Mahul (2007) recognize that in many cases the appropriate market for weather index insurance may not be individual households but instead local-level risk aggregators — such as MFIs, farmers' cooperatives, input suppliers, and, in some cases, local and national governments — who indirectly face weather risk

due to their interdependence with farmers exposed to such risk, and also face less basis risk than would an individual farmer.

2.4 Spillover Effects: Is Formal Insurance Crowding out or In?

Several studies suggest that the availability of some form of formal insurance may crowd out informal insurance, especially where informal insurance contracts are self-enforcing. A public safety net, for example, could increase the value of autarky relative to that of remaining in a reciprocal informal insurance arrangement, thus reducing the incidence of informal risk sharing and the insurability of idiosyncratic shocks. This is found to be the case in Ethiopia, where rural households in villages receiving public aid suffer greater consequences of idiosyncratic crop shocks compared to those in villages where no food aid is present (Dercon and Krishnan 2003). Attanasio and Rios-Rull (2000) find similar results using data from the PROGRESA program in Mexico; in this case, compulsory public insurance designed to protect against aggregate shocks is actually welfare reducing, crowding out private insurance arrangements that protect individuals from variable consumption in the face of idiosyncratic shocks.

As mutual support networks within communities tend to be somewhat frail, their continued existence relies on incentive compatibility of all members; no individual can have a motivation to want to leave the group, as commitment is not likely fully enforceable in these arrangements and any defection undermines the risk-sharing system (Clarke and Dercon 2009). At the same time, the poorest of the poor may gain inclusion into informal social safety nets if index insurance were available to prevent asset losses in the face of catastrophic risk. Santos and Barrett (2011), for example, find a middle-class bias in informal reciprocal lending arrangements

among Ethiopian pastoralists, whereby those who are "too poor" (i.e., close to or below a dynamic asset threshold) are less likely to be offered in-kind livestock loans from community members.

Alternatively, existing informal risk-sharing networks may crowd out formal insurance. Demand for voluntary health insurance in Vietnam is found to be lower among households with a strong history of private transfers among kinship groups (Jowett 2003). Rosenzweig and Wolpin (1993) also suggest that formal insurance can lower household welfare, precisely because these households have access to informal mechanisms that are more cost effective. This is particularly pertinent with the case of index insurance, where actual losses may vary significantly from indemnity payments due to basis risk.

In addition to the relationship between formal and informal insurance, formal insurance can interact with other financial services. The challenge of offering insurance to the poor has, fortunately, been mitigated by the evolution of microcredit. In turn, the potential for synergy between the two financial products is promising: the presence of MFIs can facilitate the distribution of insurance policies to those who are already bank clients, and existing creditor-lender relationships may lessen any distrust of insurance companies among prospective policyholders; at the same time, having borrowers who are insured against catastrophic risk in particular will lower the probability of MFIs becoming insolvent due to systematic default (Barnett, Barrett and Skees 2008). In other words, insured households make better credit applicants. Thus, access to index insurance may also expand the population of impoverished households that has access to credit, especially in agricultural regions. While uninsured

borrowers are left vulnerable to catastrophic shocks and may choose not to borrow at all as a result (Armendariz and Morduch 2005), if insured, households can borrow both ex post for consumption smoothing and ex ante for productive activities knowing that they are less likely to default and face severe penalties for doing so.

There are, however, cases that seem to counter the hypothesis of insurance spurring credit demand. In a previously mentioned randomized controlled trial, for example, Malawian farmers' demand for credit is found to decrease when loans are bundled with a rainfall insurance contract, even though there is considerable risk of income loss due to drought (Gine and Yang 2009). In this study, higher levels of education increase take-up rates of the insured loan, while education is not significantly correlated with the choice to take out an uninsured loan. In another randomized experiment, this time offering indemnified loans to farmers in Ghana, no significant difference is found in loan uptake among treatment and control groups (Karlan, Kutsoati, McMillan and Udry 2011), although farmers in the treatment group are found to shift production to a more perishable, and therefore riskier, crop.

While the ability to obtain index insurance may increase credit access, there is additional concern for the possible negative spillover effects that might arise from insuring the poor. For example, while index insurance may eliminate moral hazard in insurance markets, it may increase moral hazard in other markets if the policy is not carefully designed. Clarke and Dercon (2009) argue that insurance can "crowd out" credit markets by implicitly reducing the severity of punishment when households default on loans. Index insurance, by effectively increasing the minimum welfare level a household can achieve should it default, reduces incentives for repayment and, in

turn, results in lenders having to cut back on the amount of credit they can profitably offer to clients. It is noteworthy that the converse may also be true: index insurance could reduce moral hazard in credit markets under special circumstances. In Morocco, for example, the country's public agricultural bank has a policy of forgiving farm loans following drought; if weather insurance were made available, borrower repayment discipline may increase as drought would be less likely to influence the ability to repay (Skees et al. 2001).

3 The Model

3.1 The Representative Agent Model

Consider an infinitely lived, representative agricultural household that may borrow a loan of a fixed quantity, L, but not save, in any given period. In practical terms, that the loan size is set reflects a situation in which credit is offered for a specific investment (e.g., the loan amount is precisely chosen to be just enough for an inputs package). Note that, despite the design of the lending contract offered and due to the fungibility of money, a borrowing household need not use the funds for their intended purpose and may instead spend the loan on own consumption.[**] If the household chooses to take out a loan, it must also purchase an index insurance contract that is linked to the loan; the premium is deducted from the borrowed amount before the loan is disbursed. This contract can cover only the value of the loan or, in the alternative, the entire expected value of the crop; implications of the type of loan-coupled insurance coverage will be discussed subsequently. The household may later choose to default on its loan, but faces a punishment if it does so.

[**] See, e.g., Kotir and Obeng-Odoom (2009), where Ghanaian households are found to divert a significant proportion of microcredit loans to household consumption.

For the current analysis, two scenarios are considered, both in which a household's decision to take up a loan renders mandatory the purchase of an associated index insurance contract: In Scenario 1, the farm household receives the indemnity directly; and in Scenario 2 the lender receives the indemnity, and uses the funds to reimburse itself for any unpaid debt before transferring any remaining indemnity to the borrower. In both scenarios, households may purchase insurance if and only if they opt to take out a loan.[††] The addition of a single parameter will simplify the numerical analysis and allow for both cases to be modeled under the same framework. A comparison of outcomes under both scenarios will reveal policy implications, especially where default and technology uptake decisions diverge.

The utility of the household is derived from earnings from farm production, which are stochastic. Farm production occurs through one of two channels: a traditional farming technology that requires no additional cost but results in lower average income, or a high-yield technology (e.g., fertilizer adoption) that carries an upfront cost and results in more variable income due to the sensitivity of the technology to weather risk. Households begin each period with the knowledge of their current wealth, credit, debt and technology states, and make three discrete choices to maximize the expected, discounted present value of lifetime utility of wealth:

1. To default on or repay an outstanding loan;
2. To take out an insurance-linked loan for the current period or go without borrowing; and
3. To adopt a high-yield or traditional farm technology.

[††] This condition has practical significance, as it is often the case that MFIs are chosen as distributors of agricultural insurance contracts, and thus tend offer the product to their existing client-borrowers.

For the household's dynamic optimization problem, the state variables are thus:

(i) Credit State:

$$i = \begin{cases} 1 \; if \; household \; is \; credit \; worthy \; in \; the \; current \; period; \\ 0 \; if \; household \; is \; credit \; unworthy \; in \; the \; current \; period. \end{cases}$$

(ii) Debt State: d, where a household's debt is determined by both its past borrowing and current repayment decisions.

Transitions for the debt state, which is stochastic as it is dependent on the systemic portion of income that is indemnified by the index insurance contract, follow the rule:

$$\tilde{d}' = (1 + r)L\text{Max}\{0, j' - \varphi j' h(\tilde{z})\}$$

where r is the (exogenously determined) interest rate on credit, $\tilde{z}$ is a systemic component of income, $h(\tilde{z})$ is the indemnity schedule on the index insurance contract (recalling that index insurance contracts do not cover idiosyncratic income shocks), and

$$j' = \begin{cases} 1 \; if \; household \; takes \; out \; a \; loan \; in \; the \; current \; period; \\ 0 \; if \; household \; does \; not \; take \; out \; a \; loan \; in \; the \; current \; period. \end{cases}$$

The parameter φ will be discussed momentarily. In this model, the indemnity schedule will not vary by technology choice, as the loan is intended for the purposes of technology adoption regardless of how the household actually chooses to use it. Specifically, we designate the parameter η as the portion of debt that is covered by the index insurance contract, so that $h(\tilde{z}) = \eta\tilde{z}$. As a simplification we let $\tilde{z}$ take on one of two values, so that $\tilde{z} = 1$ indicates a period in which the household experiences a systemic shock (e.g., a drought) and $\tilde{z} = 0$ is indicative of normal systemic conditions. Thus, for $\eta = 1$, a household with an outstanding loan would have its debt erased in a drought year ($\tilde{z} = 1$) and would otherwise be responsible for full repayment of the loan should it choose not to default. Let p denote the probability of a drought, so that a farm household experiences normal crop conditions with probability $(1 - p)$.

(iii) Technology State:

$$k = \begin{cases} 1 \; if \; household \; currently \; uses \; high \; yield \; technology; \\ 0 \; if \; household \; currently \; uses \; traditional \; technology. \end{cases}$$

Although the technology state is explicitly listed here, it does not appear directly in the household's value function and is instead subsumed into the state variable for wealth.

(iv) Wealth: $w \geq 0$

Wealth is composed of current, technology-contingent agricultural income; it can also include savings if the model is amended to include an additional endogenous state variable. Specifically, let $\tilde{y}_k$ represent stochastic income from technology k, for $k = 0,1$, where income is decomposed as:

$$\tilde{y}_k = \bar{y}_k(1 - \beta_k \tilde{z})\tilde{\varepsilon}_k$$

Expected income under normal conditions is $\bar{y}_k$, and is dependent on the household's choice of technology. To reiterate, $\tilde{z}$ represents a systemic shock (e.g., rainfall), which is indexable but can differentially affect income depending on the household's choice of technology. The parameter β_k corresponds to the systemic portion of income lost due to drought, and reflects the insurability of technology k through an index-based contract (the larger the β_k, the greater is the proportion of income explained by the systemic factor measured by the index, and thus the more value the insurance contract provides the household). On the other hand, the more variable the mean-one, idiosyncratic risk, $\tilde{\varepsilon}_k$, the less attractive the insurance contract is to its holder. A low β_k or a highly variable $\tilde{\varepsilon}_k$ indicates that there is a substantial amount of basis risk faced by the household if it chooses to take out a loan linked to an index insurance contract. Let σ_k denote the volatility of the idiosyncratic income factor for technology k. Finally, we assume $\tilde{z}$, $\tilde{\varepsilon}_0$, and $\tilde{\varepsilon}_1$ are mutually serially independent and identically distributed over time, and $\bar{y}_1(1 - \beta_1 p) > \bar{y}_0(1 -$

$\beta_0 p) > 0$. The latter assumption translates to expected income from the high-technology option being greater than that of the traditional option, where both income types are strictly positive.

Similar to the case of the debt state transitions, whether or not the wealth state is endogenously determined by indemnity payments depends on the scenario under which the model operates. State transitions for wealth, which is also stochastic, are characterized by the function:

$$\widetilde{w}' = \tilde{y}_{k'}\left(\tilde{z}, \tilde{\varepsilon}_{k'}\right) + (1 + r)L\text{Max}\{(1 - \varphi)j'h(\tilde{z}),\ j'h(\tilde{z}) - j'\}$$

The parameter φ, which appears in the transition functions for both continuous state variables, is used as a tool in the numerical approach to solving the model under the two scenarios, which vary only in the entity (borrower or lender) that serves as the initial claimant of the index insurance indemnity. Setting $\varphi = 0$ reflects Scenario 1, where the indemnity is paid first to the borrower. Under this regime, any indemnity payments factor into a household's disposable income, as the household that takes out an insured loan is not required to repay said loan to receive the benefits of the insurance. On the other hand, $\varphi = 1$ embodies Scenario 2, where the lender first receives any indemnities. From the household's perspective, in this case the insurance contract acts as a contingent credit contract by reducing the debt it may choose to repay on an outstanding loan. If the model is amended to allow the insurance contract to cover the systemic portion of the household's entire crop (and not solely the value of the loan), the lender will transfer to the household any indemnity payments net of its unpaid debt.

The action variables are, therefore, the credit, debt and technology choices that will transition to the endogenous state variables in the following period, i', j', and k'. Additional model parameters are:

(i) $P \equiv$ insurance premium (where insurance is coupled with a loan)

Specifically, the coupled loan-insurance contract is available at a premium of

$$P = (1 + \theta)\eta pL$$

where θ is the premium load. Thus, $\theta = 0$ reflects the case of actuarially fair insurance; $\theta > 0$ reflects actuarially unfavorable insurance (which is common in practice in private markets, as insurers must account for transactions and ambiguity costs in order to break even); and $-1 \leq \theta < 0$ reflects subsidized insurance, where a negative premium load is usually associated with government-run or donor-sponsored insurance projects – especially those in the pilot phase.

(ii) $K \equiv$ technology investment cost

In the case of a non-durable technology purchase (e.g., fertilizer), there is only a cost related with input purchase; this cost is independent of the previous period's technology choice as the investment is completely reversible and depreciates after one crop season. If the goal of a lending project is to induce technological adoption among smallholders, it may be the case that the lender sets $L \geq K$, so that the borrowing household does not face liquidity constraints if it wishes to invest in the high-technology farming option.

(iii) $\gamma \equiv$ cost parameter that captures the stigma of default when a household is or becomes credit unworthy.

Note that γ is an additional penalty, as a defaulting household is also unable to borrow freely in the future as would one that is credit worthy. One way to consider the stigma parameter is as a

social cost of default, where households who have reneged on formal insurance-credit contracts may be less likely to receive informal loans from extended family or community members.

(iv) $\mu_j \equiv$ exogenous probability of reinstatement into creditworthiness, conditional on a household's current credit state, where $\mu_j \in (0,1]$, for $j = 0,1$.

Because a household that is creditworthy will remain so until it chooses to default, $\mu_1 = 1$ and $\mu_0 = \mu$, where a higher μ indicates a lesser punishment for default. This would be the case, for example, where lenders are unable to detect when clients have previously defaulted due to a lack of a well-functioning credit rating agency or even the ability to identify an individual. Let $\bar{\mu}_j = 1 - \mu_j$.

Recalling the two scenarios in the model, the farm household's dynamic optimization problem can now be expressed in the form of a single Bellman equation whose value function represents the maximum expected present value of lifetime utility, $V_i(w, d)$, attainable, given the household's creditworthiness, i, disposable wealth, w, and debt, d, at the beginning of the period. To summarize, under Scenario 1, indemnities are made directly to the borrower and any insurance payments factor into the state variable for wealth, as they become part of the household's disposable income. Under Scenario 2, indemnities contribute to the debt state variable and serve to reduce the amount a non-defaulting household must repay on its loan. Again, the second case is one of contingent credit, where the insured borrower cannot, after realizing a systemic shock, take the money and run.

Recalling the state transition functions for w and d, the household's Bellman equation takes the form:

$$V_i(w,d) = \text{Max}_{\substack{i',j',k' \in \{0,1\} \\ j' \le i' \le i}} \{u\,(w - i'd + j'(L-P) - k'K) - \gamma(1-i') + \delta E_{\tilde{z}\tilde{\varepsilon}}[\bar{\mu}_{i'} V_0(\tilde{w}', \tilde{d}') + \mu_{i'} V_1(\tilde{w}', \tilde{d}')]\}$$

The constraint on j' restricts a household from borrowing if it has defaulted in the past or is currently choosing to default. Once a household has defaulted, it cannot take action to regain its status of creditworthiness; instead, only the exogenous probability μ_i dictates a credit unworthy household's ability to re-enter the credit market.

Let the farm household's utility function be twice continuously differentiable, strictly increasing and strictly concave, with utility increasing in wealth and $lim_{c \to 0}\, u'(c) = \infty$. Note that this functional form implies risk aversion. For the numerical analysis that will be presented in the subsequent section, we assume period utility is isoelastic, taking the form $u(c) = \frac{c^{1-\alpha}}{1-\alpha}$, so that farm households display constant relative risk aversion. Finally, $\delta \in (0,1)$ is the household's time discount factor.

3.2 The Heterogeneous Agent Model

In order to broaden the analysis to one of a village economy, we now expand the model to allow for heterogeneous agents. While, for the purposes of this exercise, agents do not differ in preferences, they do experience distinct histories of shocks over time. Thus, the representative agent model can be straightforwardly transitioned to a heterogeneous agent model through Monte Carlo simulation. With such a model, ergodic distributions of wealth, creditworthiness, loan and insurance uptake and technology adaptation can be simulated. When calibrated to fit

the conditions of an economy of interest, the model is especially useful in comparing welfare effects of various development policies.

4 Method and Results

4.1 Finding a Numerical Solution

To solve the farm household's Bellman equation using numerical techniques, it would normally be the case that collocation be employed under various parameterizations of the model. The method of collocation numerically approximates a Bellman equation not by requiring the value function to be satisfied everywhere, but instead by ensuring that it holds with equality at a given number of judiciously chosen nodes (Miranda and Fackler 2002). Collocation uses a series of known basis functions, $\varphi_j(x)$, whose unknown coefficients, c_j, are estimated using a series of rootfinding routines, one for each node at which the Bellman is required to be satisfied. Thus, this method reduces a problem of infinite dimension to a finite one, where residuals can be calculated to analyze the goodness of fit of the approximation. The collocation method is a special case of interpolation, where an approximating function – a linear combination of basis functions – is set to agree with the original function at n chosen nodes, such that:

$$f(x) \approx \hat{f}(x) = \sum_{j=1}^{n} c_j \, \varphi_j(x)$$

Due to the expected shape of the optimal path (specifically, a kink in the value function is anticipated at the net worth level at which households switch from one discrete choice to another), either Chebychev or cubic spline interpolation can be used to approximate the Bellman equation; in general, the use of Chebychev basis functions and nodes is preferred when the value function is smooth. Collocation methods employing cubic spline interpolation will be used in

future extensions of this model, where savings is allowed to interplay in the household's decision making process.

Without savings, however, and with the assumption that draws of the systemic income component, $\tilde{z}$, belong to a two-point distribution (again, representing "normal" and "drought" seasons), the model can be solved numerically without resorting to collocation methods. Although the state variables w and d appear at first glance to be continuous, the construction of the model instead allows for only a finite number of realizations of both disposable wealth and debt states. This is, in part, also due to the discretization of the random idiosyncratic income component through the use of Gaussian quadrature, by which n discrete values are assigned a probability mass such that the discrete approximating distribution has the same $2n-1$ absolute moments as the original, continuous distribution. We assume that farm-specific income can take on one of m values[‡‡] per technology in any given period, and that this idiosyncratic income component is lognormally distributed. To solve the farm household's value function, therefore, we use a root-finding algorithm similar to that employed in Miranda and Gonzalez-Vega (2011).

4.2 Results under Base Parameterization

In addition to the Scenarios 1 and 2 presented in this paper, in the numerical analysis we also include two additional cases, one in which credit, but not insurance, is available to the household, and another in which both credit and insurance are independently available. Thus, there exist reference points to which we compare the two initial policy scenarios of interest.

[‡‡] In simulation results presented here, $m = 21$.

Under each of the four cases we use Monte Carlo methods to run 100 thousand simulations, from which we calculate five long-run averages that characterize the relevant economy:

1. Rate of Creditworthiness;
2. Rate of Loan Uptake;
3. Rate of High Technology Adoption;
4. Rate of Insurance Uptake; and
5. Rate of Default

A list of the base parameter values can be found in the Appendix as Table 1.

Results (presented in the Appendix as Table 2) indicate that, as expected, creditworthiness is the highest for Scenario 2, where insurance is available if and only if a household takes out a loan, and where any resulting indemnities are first paid to the bank. A noteworthy comparison is to be made between default rates under the baseline case of credit without insurance and that of independent credit and insurance availability. Default rates are higher in the latter regime, despite the fact that households have access to – and choose to purchase – insurance. This seems to indicate that financial products that are not interlinked may not complement one another. This result supports the literature of negative spillover effects that was discussed previously. In Scenario 1, default rates are higher than in Scenario 2, which corroborates the notion of perverse incentives when fewer punishments exist for default. We offer two observations as to why default is lower in Scenario 1 than in the other two reference cases: (i) compared to households that can only access credit, the availability of insurance protects subsistence households against downside risk, diminishing the probability of an extremely low realization of disposable income; and (ii) the linkage between the credit and insurance contracts not only results in a household

being barred from taking out credit should it default (as is the case where credit and insurance are separately available), but also prohibits a credit-unworthy household from being insured.

Rates of borrowing do not differ greatly moving from Scenario 1 to Scenario 2, although there is a divergence in loan uptake when comparing the cases of interlinked credit-insurance contracts with the two reference cases. The higher propensity to borrow under regimes offering bundled products seems to indicate that it is the insurance – not the credit – that is of relative value to the household. This finding is especially visible when looking at the case of independent credit and insurance contracts: while only 16 percent of the population opts to borrow, a whopping 97 percent chooses to insure.

A principal motivation of this paper is to examine whether or not insured households are more likely to adopt technology. At first glance, the answer is yes. Nevertheless, more investigation is required to examine the motivations for subsistence households' choice of farming technology. High-technology use is the most prevalent where insurance can be purchased separately; this is, however, in part due to the ability to default on a loan with very little punishment, as discussed previously. Along similar lines, households under Scenario 1 are slightly more likely to adopt technology than their counterparts under Scenario 2, as the former class of households can default with indemnity payments in their pockets. That Scenario 2 and credit-only households are equally likely to adopt technology is somewhat perplexing from a policy standpoint; on the other hand, one need only observe the juxtaposition of default rates between the two regimes – about half of the households in Scenario 2 default, whereas almost 80 percent of households default when they cannot access insurance.

Now, we examine the within-scenario behavior of agricultural households, with close attention paid to the technology uptake decisions among the insured and uninsured portions of society. In Scenario 1, just over 82 percent of insured borrowers are high-technology users while just under 59 percent of those uninsured also adopt the technology. Thus, there is a clear implication of insurance-induced technology uptake among this population.

In contrast, only 66 percent of those insured under Scenario 2 adopt the high technology farming option, whereas almost 74 percent of the uninsured do so under the same regime. This seemingly counterintuitive result stems from the nature of the insurance contract; because fewer borrowers default under Scenario 2 relative to Scenario 1, the disposable wealth of the insured portion of the population is lower. Thus, investment in technology further depletes disposable wealth, making the option unattractive to a significant class of insured borrowers. Interestingly, the insured, traditional farming population in Scenario 2 therefore receives an indirect benefit of the availability of a high-technology farming option. Because the loan-coupled insurance is made available to motivate high-technology farming – the actual employment of which cannot be enforced – non-adopters can enjoy higher consumption through the use of loan funds, which do not have to be repaid in times of drought.

As for the remaining case in which insurance is available (where credit and insurance are separately available), the uninsured population does not adopt technology at all, while over 78 percent of those who choose to be insured also choose high-technology farming. Again, as in Scenario 1, a higher technology adoption rate relative to Scenario 2 is also a product of the

insured household's ability to default on its loan. In addition, under the independent credit-insurance regime, households do not have to take out loans that must be repaid in "normal" seasons, and thus may have more disposable income with which to invest in technology. We re-emphasize the fact that insurance uptake is much higher than credit uptake for this population. Thus, purchasing insurance isn't simply a means to obtain credit, but instead is a hedge against drought conditions. Because the high technology option is more profitable on average, insured farm households would be wise to adopt; in good years, the increased income more than covers the premium, and in bad, households are compensated through the indemnity payment.

5 Sensitivity Analysis

5.1 Risk Aversion, Technology Adoption and Coverage Type

Rural households that practice subsistence agriculture are risk averse, and often extremely so. There are means of eliciting risk preferences through survey questionnaires, and risk aversion measures have been estimated in the development literature. However, to the extent that these measures are subject to error, it is important to study policy implications of insurance programs under different assumptions on the level of risk aversion among households. Varying the coefficient of relative risk aversion in a household's period utility function generates an interesting, albeit intuitive, result. The more risk averse a household, the greater the impact of the availability of insurance on technology adoption. In addition, the magnitude of the effects of insurance on technology adoption – especially where index insurance is independent of credit – tend to fluctuate depending on the type of insurance coverage offered.

Recall that contingent credit refers to the case in which only the loan is insured by the contract, and, in the alternative, credit-linked insurance refers to the case in which a larger portion of the farm household's income is insured. In the numerical analysis, the latter case is simulated by choosing $\eta > 1$.[§§] Holding all other parameters at their base levels, relative to a case in which only credit is available, a more risk averse household is more likely to adopt the high-yield technology under both contingent credit and credit-linked insurance contracts, although under bundled contract schemes, technology uptake is much more sensitive to the level of risk aversion than to the level of insurance coverage. This result holds regardless of to whom the assignment of initial claimant is given. Figures 1 and 2, which are included in the Appendix, illustrate these results.

Technology adoption is highly responsive to the level of coverage in the case of credit and insurance contracts being separately available to the farm household, likely due to the fact that households can insure without having to incur the interest that comes with the loan contract; in addition, default on credit is also an option under this regime, and does, in fact, occur at a high rate (*see* Figure 3). While technology adoption is not as sensitive to the level of coverage among risk averse households that must jointly purchase credit and insurance, the rate of default for these households is found to steadily decline as insurance coverage increases; as seen in Figure 4, this is not the case when credit and insurance are not interlinked.

The finding regarding coverage level is interesting in that it indicates that there may not be significant welfare gains from offering full insurance for crops; if households are only

[§§] For the numerical sensitivity analysis, under otherwise base parameterization, a credit-linked index insurance contract is one characterized by $\eta = 2$ (*see* Table 3).

moderately risk averse, insuring the investment in technology seems to be enough to induce adoption. Relatively more risk averse households, on the other hand, are less likely to adopt technology even when coverage is extended. This result is likely driven by the level of basis risk faced by households, as the idiosyncratic portion of farm income is uninsurable; in essence, under the index insurance schemes presented in this paper, while such arrangements often lower costs incurred by the buyer, full insurance is not possible. In addition, varying the load on the insurance contract would also change this result, with technology adoption increasing under subsidized insurance (negative load) as households would not face an upfront reduction in current consumption stemming from the premium payment. The issue of insurance subsidies is addressed in the following subsection.

5.2 Premium Load and Effect of Subsidized Insurance

One consequence of incomplete financial markets in developing countries is that, although credit is available, rural households may be hesitant to take out a loan if they are without means to manage downside risk; because they risk default with uninsured credit, they simply refrain from borrowing altogether. The findings of this analysis offer supporting evidence of this hypothesis, as loan take-up rates are higher for bundled contracts. This holds under actuarially fair premium loads, and even on loads up to 0.5, after which the percent of the population that chooses to take out a loan tends to converge for all cases.

Especially interesting are the results when the insurance premium is subsidized ($\theta < 0$) under the two regimes in which insurance and credit are bundled. With negative premium loads, not only is insurance uptake higher, but loan uptake increases, technology adoption increases, and

default rates decrease, and do so rather drastically. While, in these cases, it seems that households are taking out loans merely to get the insurance benefits they would otherwise be unable to access, the overall result seems to be positive from a policy perspective. Technology adoption under subsidized, bundled insurance is higher than under the credit-only regime; the highest technology adoption rate occurs in the case in which credit and technology are independently available (technology adoption is about 5 percent higher relative to bundled insurance schemes that are highly, but not completely, subsidized), but in this case the default rate hovers around 80 percent. This is in stark comparison to the case of bundled credit and insurance schemes – regardless of the assignment of initial claimant – as default rates for this class of borrowers falls to near zero. It should be noted that, at premium loads above 0.5, the rate of default for bundled credit-insurance households increases. Where the bank is the initial claimant of indemnities, this rate converges to that of the credit-only and independent credit-insurance regimes, while for households that lay initial claim to indemnities the default rate is above 90 percent, exceeding that of the other regimes. Figures 5, 6 and 7 in the Appendix illustrate these results.

5.3 More on Default Rates: The Roles of Social Stigma and Non-Polar Initial Claimancy

While the welfare of the farm household is of primary concern in this paper, examining default rates on a bank's lending portfolio is also of interest, precisely because its supply of credit to subsistence households hinges upon the sustainability and profitability of lending projects in rural areas. Thus, in the analysis, it is important to consider the conditions under which default is relatively low.

In the base parameterization, the stigma parameter, γ, is set to equal zero, i.e., there is no additional penalty (other than being barred from borrowing until re-entry into creditworthiness) when a household defaults on its outstanding loan. In reality, there may be significant social costs associated with such a default, both financial and of other forms. Under the model assumptions, stigma is found to be a significant parameter in the determination of default rates, as well as technology adoption. As seen in Figure 8, default rates decline rapidly as the stigma parameter increases in value, with zero default for all credit and insurance regimes at a stigma value of about 0.05. Note, however, that, while default rates are declining, the rates of loan uptake decline as well, as households who want to avoid the social stigma of credit-unworthiness can do so by simply not borrowing. Interestingly enough, the increasing the stigma parameter has a positive effect on technology adoption in all cases with the exception of that in which insurance is unavailable (*see* Figure 9). The rationalization of the result is that, with insurance available, a household will adopt the technology to increase its income, and thus will be more likely to be able to repay an outstanding loan, avoiding the stigma penalty while also maintaining adequate consumption levels. In the credit-only regime, it is intuitive that increased social penalties of default can dampen technology uptake; a household that needs credit to make a risky investment will not do so when such credit is uninsured and when social costs of loan default are high.

Finally, much emphasis in the present work has been placed on interlinked credit and insurance regimes, especially with respect to how indemnities are disbursed. Throughout this paper, we have assumed that either the household or the lender is the sole initial claimant of indemnities. If, instead, we allow for a portion of indemnities to be initially paid to each party, the results are

somewhat unexpected. While default rates are lower when the bank is the sole initial claimant, allowing for a hybrid of Scenario 1 and Scenario 2 reveals that the bank need only be assigned about 35 percent of an indemnity for default rates to be at their lowest levels (*see* Figure 10). This result will, undoubtedly, vary under other parameterizations of the model, but it is nonetheless interesting to understand the implications of the design of indemnity payment allocation under credit schemes where the purchase of insurance is mandatory.

6 Conclusion and Implications

Through the use of numerical simulation techniques, we have compared policy options regarding access to insurance and credit for subsistence farmers in a developing country setting. Results have implications for both the supply and demand sides of the credit and insurance markets, as well as for the role of insurance in technology uptake.

When households are required to purchase insurance in order to take out an insured loan, the designation of an initial claimant of indemnities paid is highly significant. In Scenario 1, where households first receive the indemnity, default rates are higher, resulting in a riskier portfolio of borrowers for the lending institution. In the alternative, when the bank first receives indemnities, so that the insurance contract serves as a contingent credit contract for the borrower, default rates are relatively lower. In the former case, indemnity payments contribute to a household's disposable wealth, making default and autarky (until exogenous re-entry into the credit market) more attractive. In the latter, a household that has an outstanding loan is disincentivized from reneging on the loan contract: in good years, income is high enough that a risk-averse household would derive utility from consumption smoothing through the purchase of insurance, for which

creditworthiness is a requirement; in bad years where the loan is fully covered by the indemnity, the choice to default becomes trivial, as a borrowing household has its debt erased per the terms of the contingent credit contract.

While simulations show that technology uptake is greatest under a regime in which both credit and insurance are offered independently to a farm household, default rates are also the highest under such conditions. In addition, technology uptake doesn't differ greatly among bundled schemes, regardless of to whom the index insurance indemnities initially flow; in contrast, default rates are significantly lower where insurance is a mandatory condition of loan uptake and where the bank is the initial claimant in the insurance contract. From a policy standpoint, the option of contingent credit or credit-linked insurance, where the lending institution is the initial claimant of indemnities, is seemingly the best compromise in terms of achieving both technology adoption and default rates that are acceptable relative to a case in which insurance is unavailable.

Despite its usefulness for policy analysis, the model has its limitations and would aptly benefit from extensions. For example, the incorporation of a savings choice into the household decision-making process, or an amendment of the high-technology option so that adoption requires a larger fixed investment in a durable productive asset, may prove valuable; such nuances to the model should be further considered. The most significant caveat is the model's assumption of an exogenously fixed interest rate on credit. It may be the case that important information is lost when the bank's objective function is not modeled explicitly. We simply assume for tractability that credit is supplied to meet the demands of households; in reality, high default rates may induce a lender to increase rates on credit, or, in the alternative, to use non-price rationing by

restricting the quantity of loans available. Thus, while the current analysis allows for ad hoc, side-by-side comparison of credit-insurance options when the welfare of the farm household is of utmost interest, the model as-is does not afford an in-depth look at the implications of the policies outlined in Scenarios 1 and 2 on credit supply and interest rates. As an attempt to tackle this shortcoming, future research will endogenize the interest rate on credit, where lower long-run default rates will trigger lower interest rates. Thus, a bundled credit-insurance policy that lowers default will result in a positive feedback loop, through which households will reap future welfare gains by facing a lower cost of credit.

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APPENDIX

Table 1

Definition of Base Parameters of the Model

Parameter	Value	Definition
α	2.00	Coefficient of Relative Risk Aversion
L	0.20	Loan Size
r	0.20	Interest Rate on Loan
γ	0.0	Stigma of Default
μ_0	0.20	Probability of Regaining Creditworthiness, $i = 0$
K	0.16	Cost of High-Technology Farming
$\bar{y}_0$	1.00	Expected "Normal" Income, Low Tech
$\bar{y}_1$	1.30	Expected "Normal" Income, High Tech
β_0	0.20	Percent Income Shortfall in Drought, Low Tech
β_1	0.40	Percent Income Shortfall in Drought, High Tech
σ_0	0.10	Volatility of Idiosyncratic Income, Low Tech
σ_1	0.20	Volatility of Idiosyncratic Income, High Tech
p	0.20	Probability of Drought
η	1.0	Percent of Loan Insured
θ	0.00	Insurance Loading Factor
δ	0.90	Time Discount Rate

Table 2

Simulated Long-Run Averages of Key Economy Indicators, Base Parameterization

Variables	Credit Only, No Insurance	Independent Credit/Insurance	Bundled Contract, HH Initial Claimant	Bundled Contract, Bank Initial Claimant
1. Credit Worthy	0.505	0.489	0.524	0.534
2. Have Loan	0.158	0.159	0.225	0.232
3. High Technology	0.621	0.790	0.632	0.620
4. Have Insurance	0.000	0.972	0.225	0.232
5. Default	0.782	0.805	0.527	0.503

Table 3

Relationship Between Insurance and Technological Adoption (Entries are Percent of Total Population)

	Insured	Uninsured	Total
Credit Only			
1. Traditional Technology	0.000	0.365	0.365
2. High Technology	0.000	0.635	0.635
Total	0.000	1.000	
Independent Credit/Insurance			
1. Traditional Technology	0.211	0.026	0.237
2. High Technology	0.763	0.000	0.763
Total	0.974	0.026	
Bundled, HH Initial Claimant			
1. Traditional Technology	0.039	0.323	0.362
2. High Technology	0.182	0.456	0.638
Total	0.221	0.779	
Bundled, Bank Initial Claimant			
1. Traditional Technology	0.073	0.292	0.365
2. High Technology	0.187	0.448	0.635
Total	0.260	0.606	

Table 4

Sensitivity Analysis: Rate of Technology Adoption under Two Insurance Schemes

Regimes	Credit Only, No Insurance	Independent Credit/Insurance	Bundled Contract, HH Initial Claimant	Bundled Contract, Bank Initial Claimant
1. Low Risk Aversion ($\alpha = 2$), Contingent Credit ($\eta = 1$)	0.621	0.790	0.632	0.620
2. Low Risk Aversion ($\alpha = 2$), Credit-Linked Insurance ($\eta = 2$)	0.621	0.880	0.664	0.659
3. High Risk Aversion ($\alpha = 4$), Contingent Credit ($\eta = 1$)	0.128	0.566	0.387	0.361
4. High Risk Aversion ($\alpha = 4$), Credit-Linked Insurance ($\eta = 2$)	0.128	0.728	0.383	0.382

Figure 1

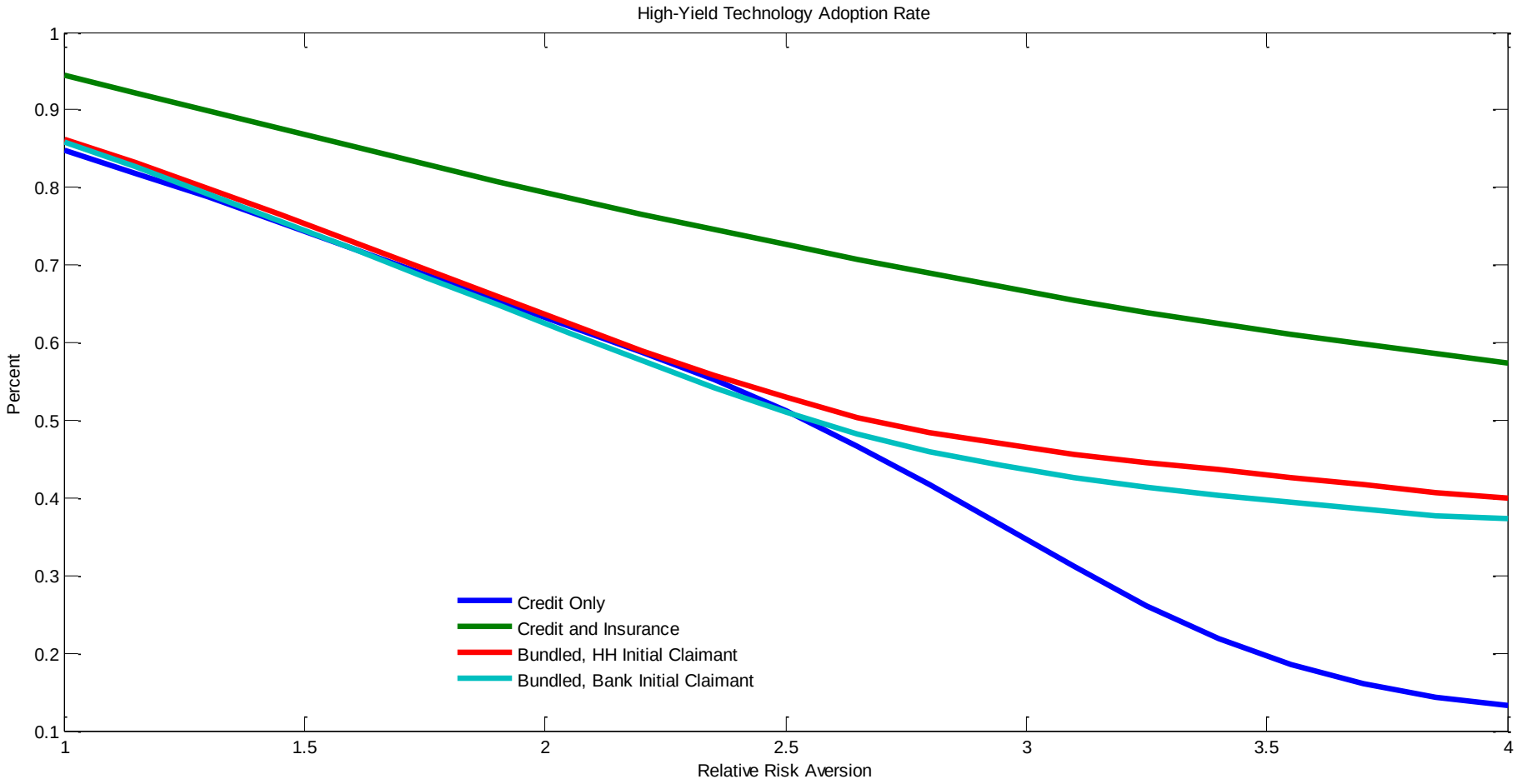

High-Yield Technology Adoption Rate
Percent
Relative Risk Aversion
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
1
1.5
2
2.5
3
3.5
4
Credit Only
Credit and Insurance
Bundled, HH Initial Claimant
Bundled, Bank Initial Claimant

Figure 2

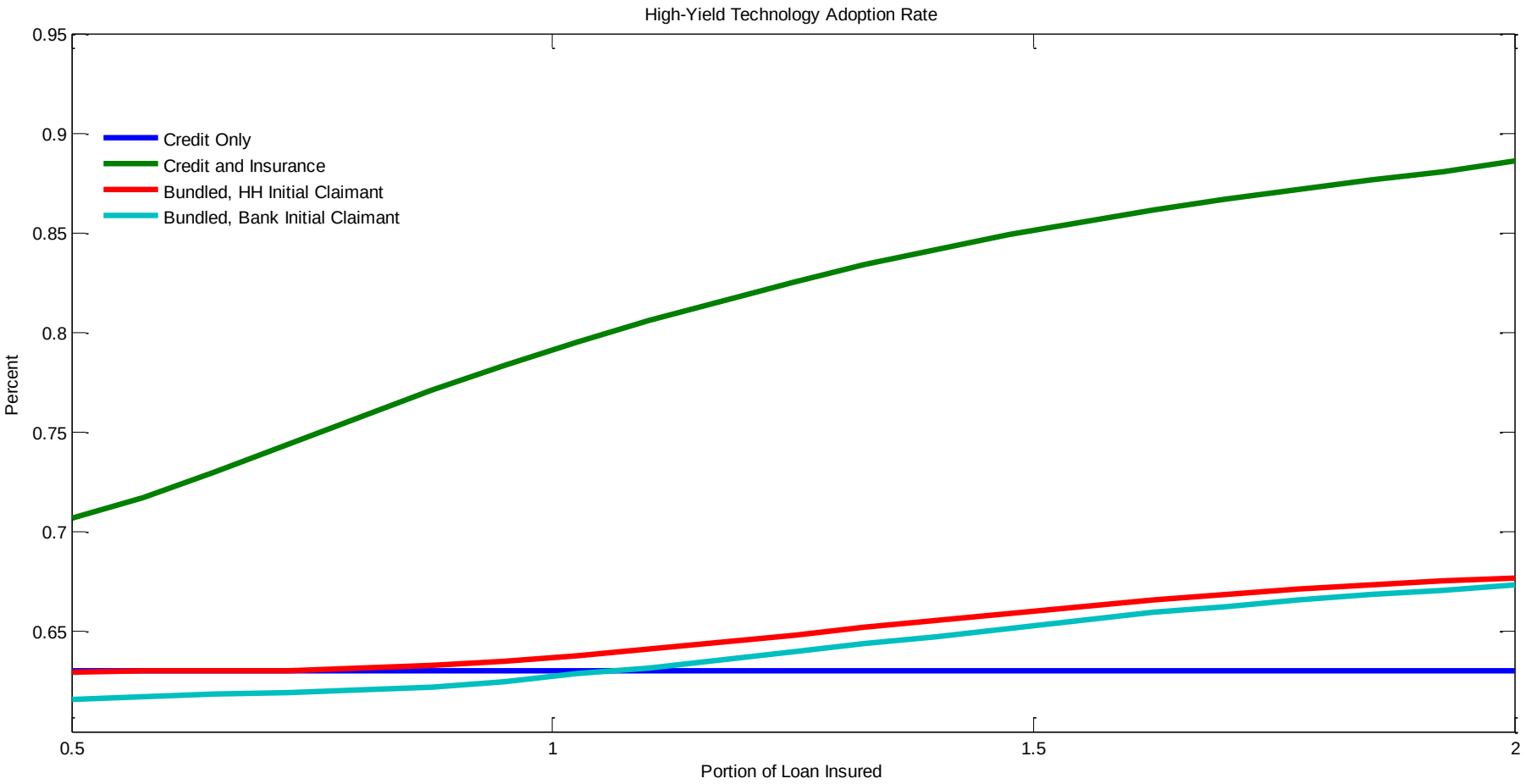

High-Yield Technology Adoption Rate
Credit Only
Credit and Insurance
Bundled, HH Initial Claimant
Bundled, Bank Initial Claimant
Percent
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.5
1
1.5
2
Portion of Loan Insured

Figure 3

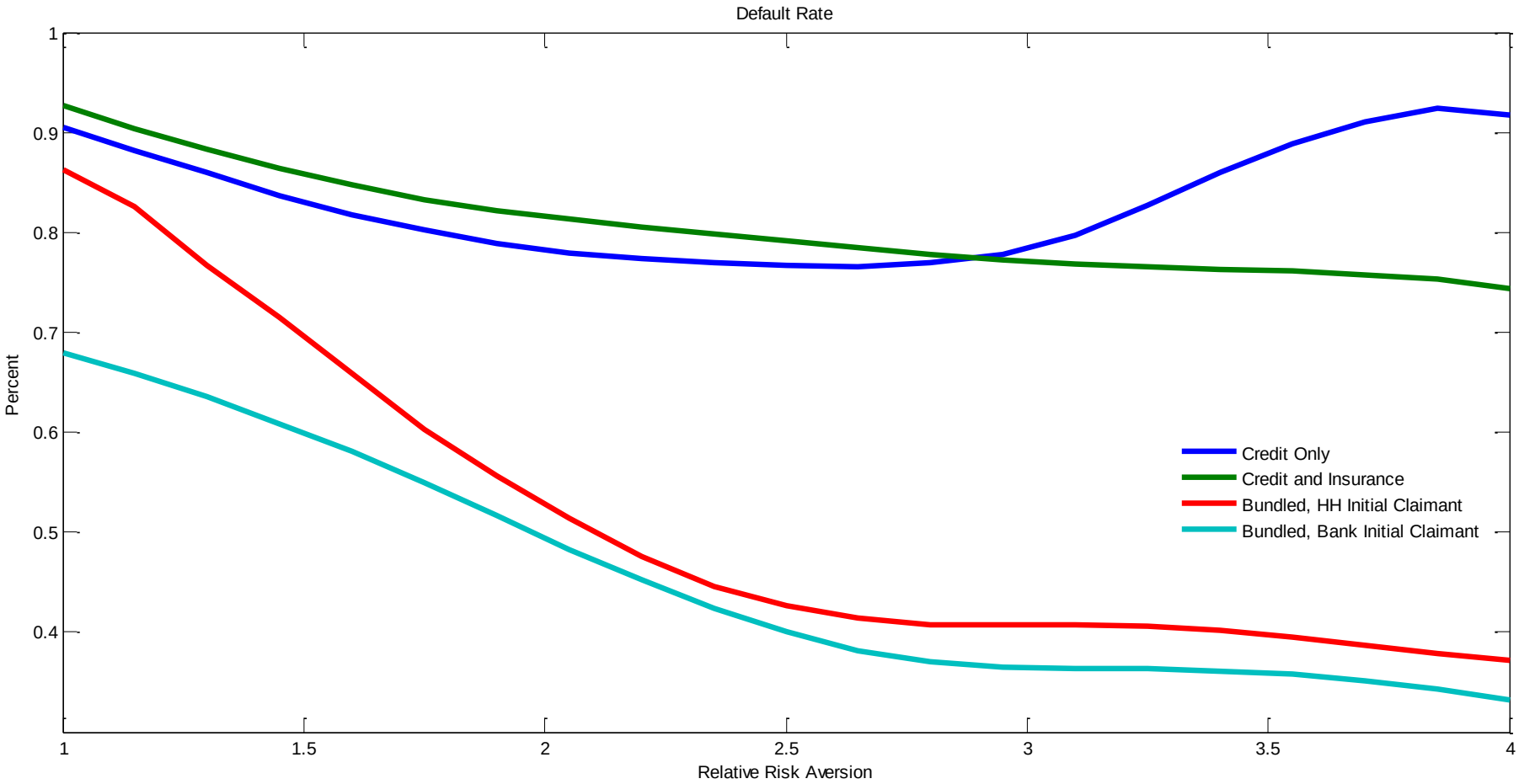

Default Rate
Percent
1
0.9
0.8
0.7
0.6
0.5
0.4
1
1.5
2
2.5
3
3.5
4
Relative Risk Aversion
Credit Only
Credit and Insurance
Bundled, HH Initial Claimant
Bundled, Bank Initial Claimant

Figure 4

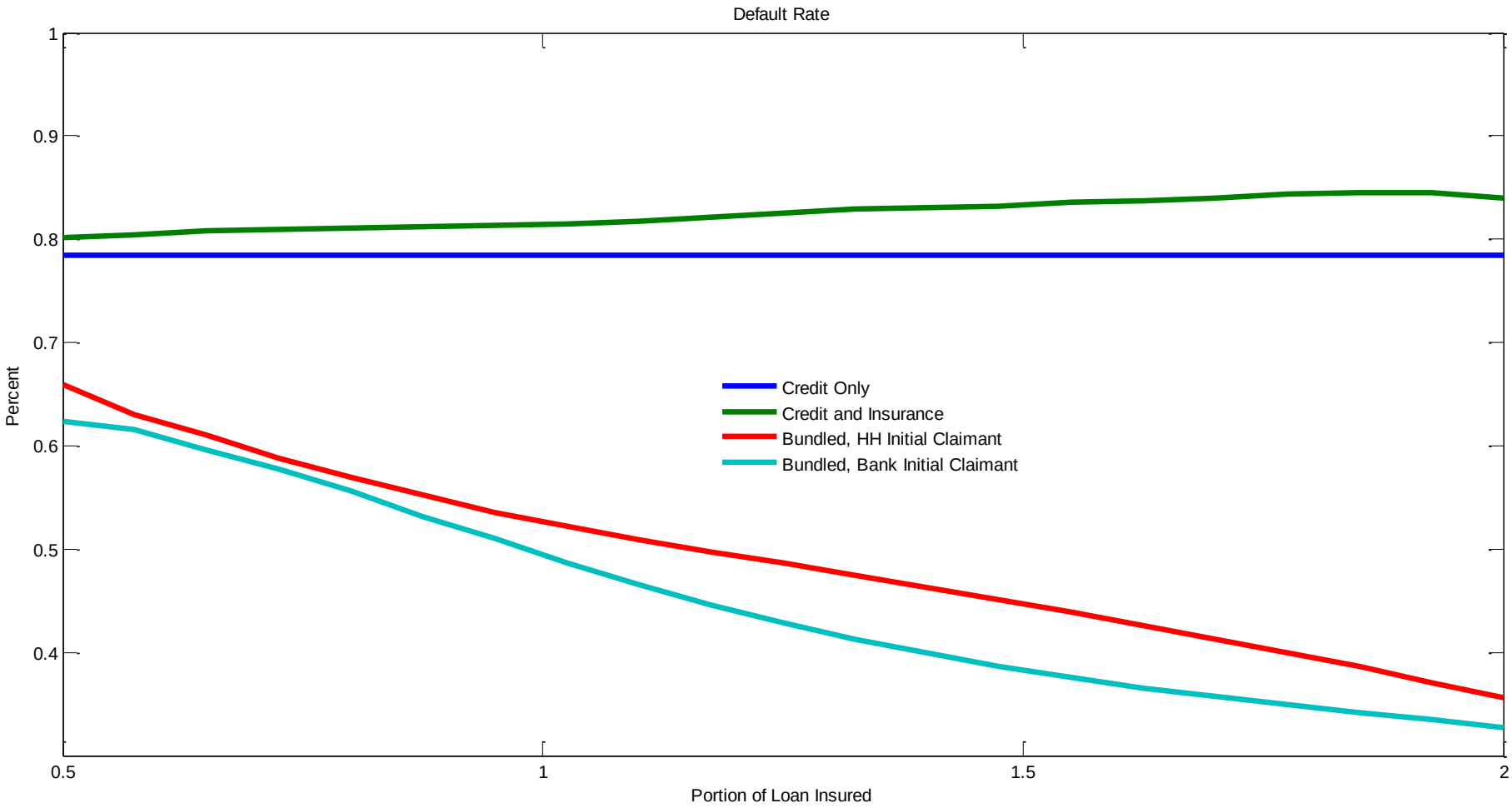

Default Rate
Percent
1
0.9
0.8
0.7
0.6
0.5
0.4
0.5
1
1.5
2
Portion of Loan Insured
Credit Only
Credit and Insurance
Bundled, HH Initial Claimant
Bundled, Bank Initial Claimant

Figure 5

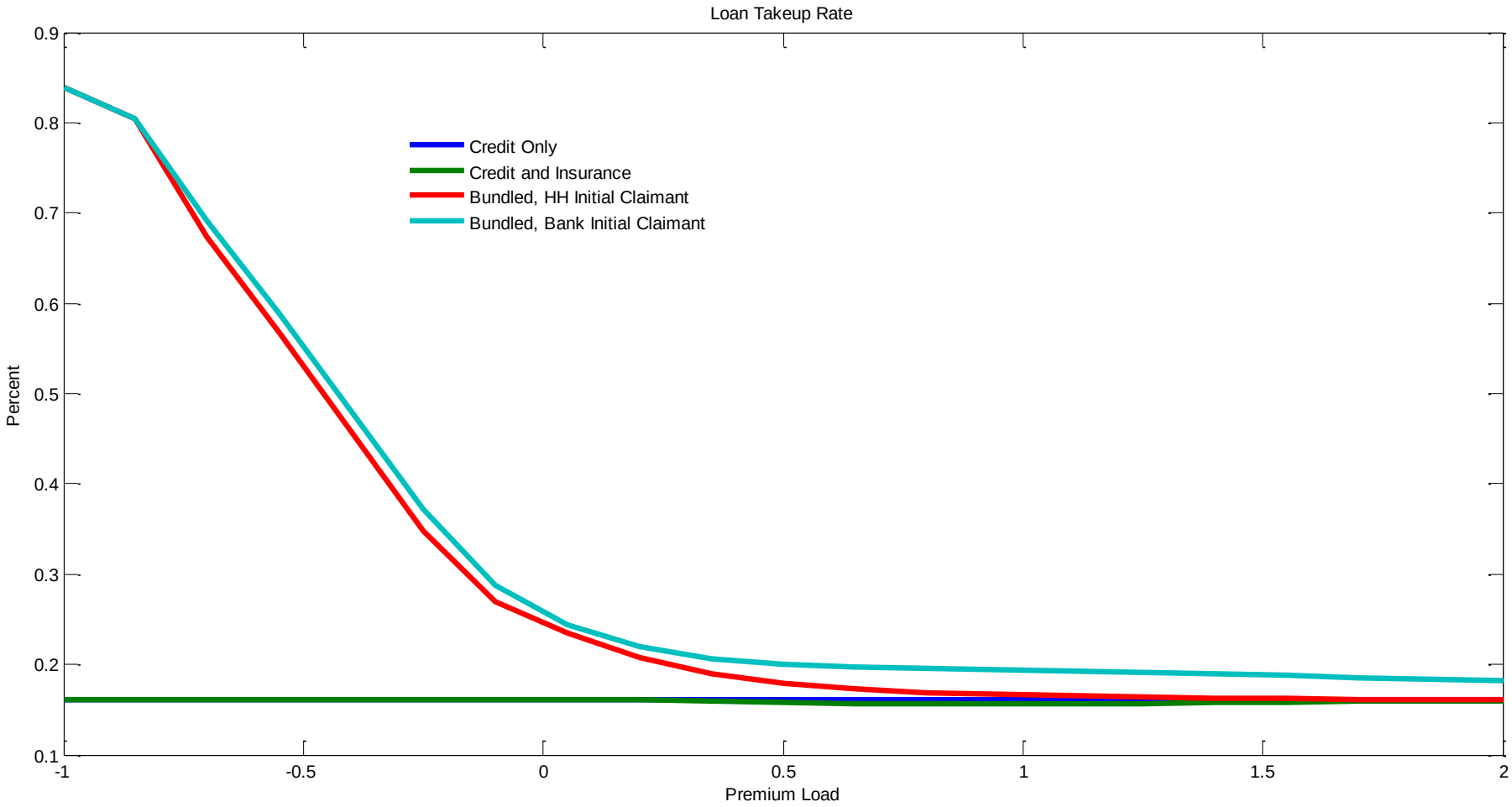

Loan Takeup Rate
Credit Only
Credit and Insurance
Bundled, HH Initial Claimant
Bundled, Bank Initial Claimant
Percent
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
-1
-0.5
0
0.5
1
1.5
2
Premium Load

Figure 6

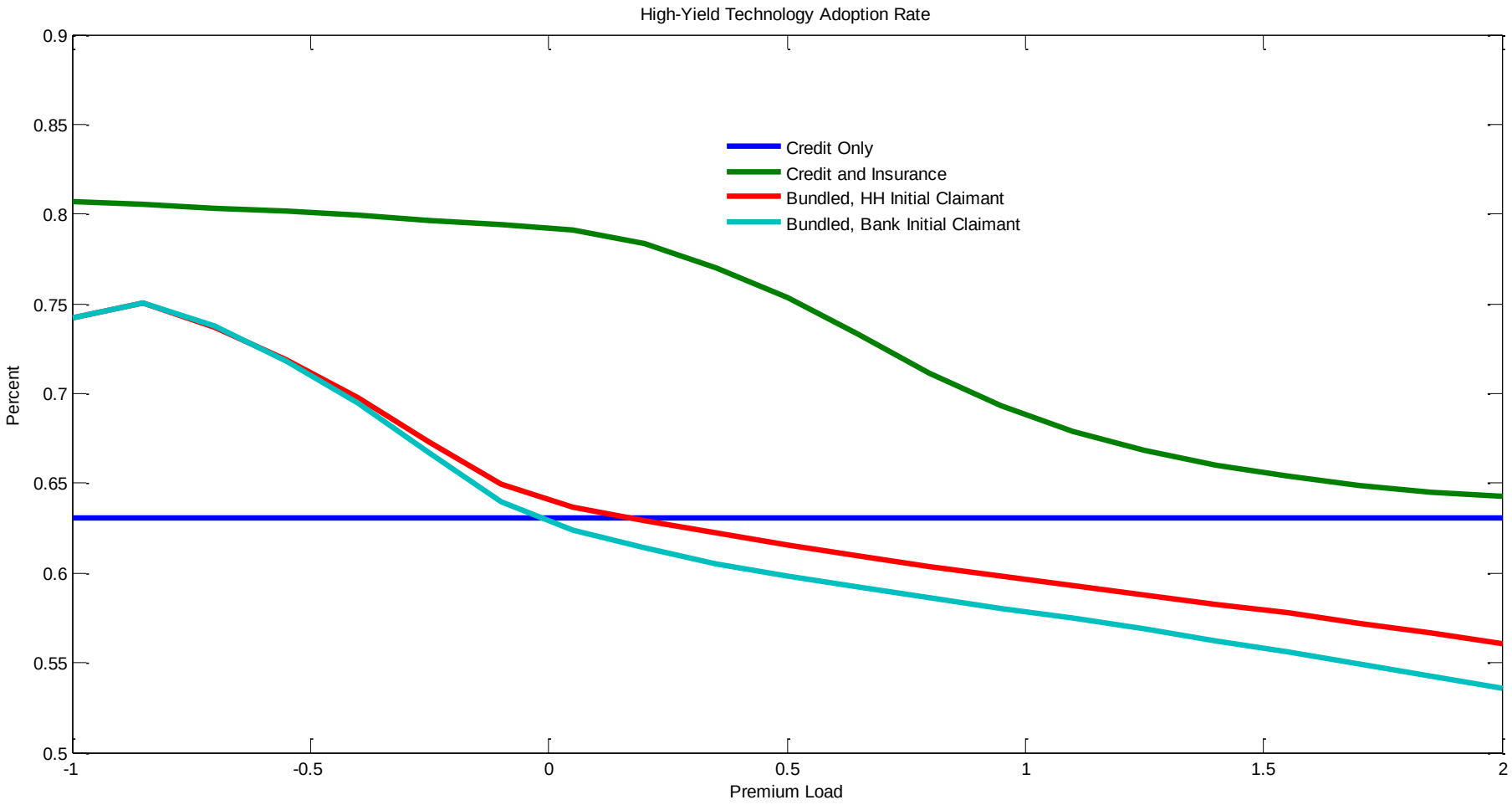

High-Yield Technology Adoption Rate
Credit Only
Credit and Insurance
Bundled, HH Initial Claimant
Bundled, Bank Initial Claimant
Percent
Premium Load
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
-1
-0.5
0
0.5
1
1.5
2

Figure 7

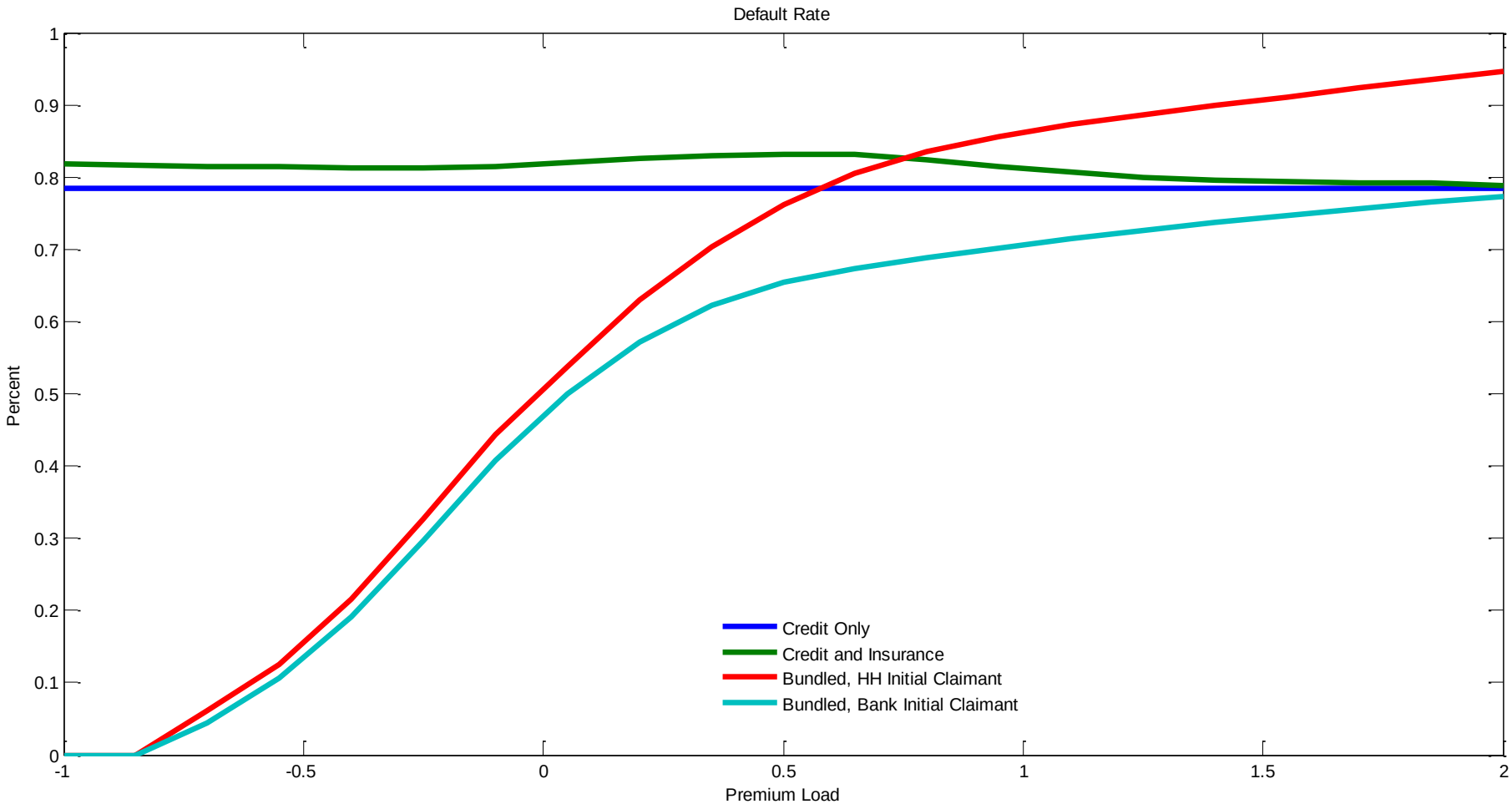

Default Rate
Percent
Premium Load
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-1
-0.5
0
0.5
1
1.5
2
Credit Only
Credit and Insurance
Bundled, HH Initial Claimant
Bundled, Bank Initial Claimant

Figure 8

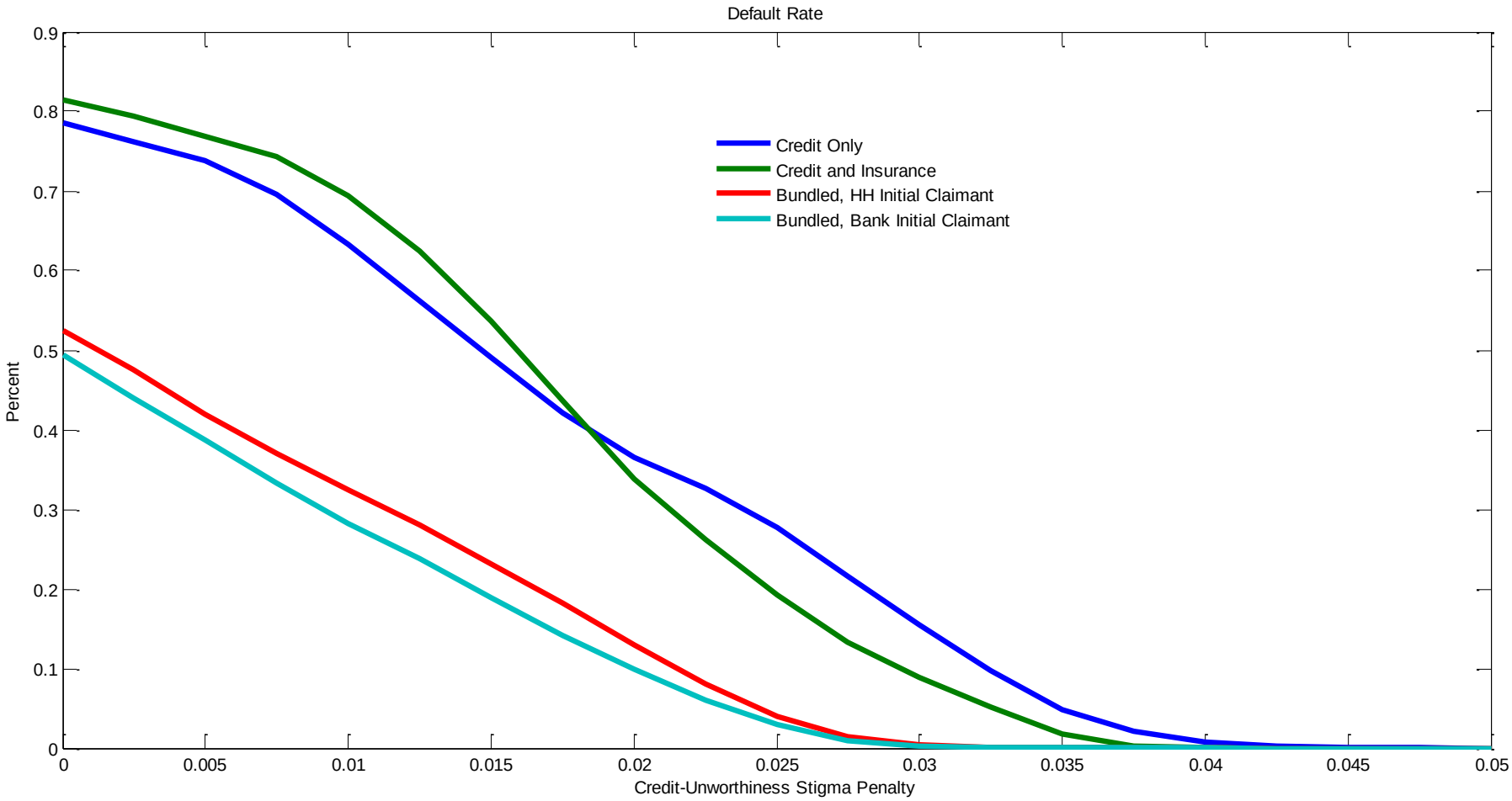

Default Rate
Credit Only
Credit and Insurance
Bundled, HH Initial Claimant
Bundled, Bank Initial Claimant
Percent
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045
0.05
Credit-Unworthiness Stigma Penalty

Figure 9

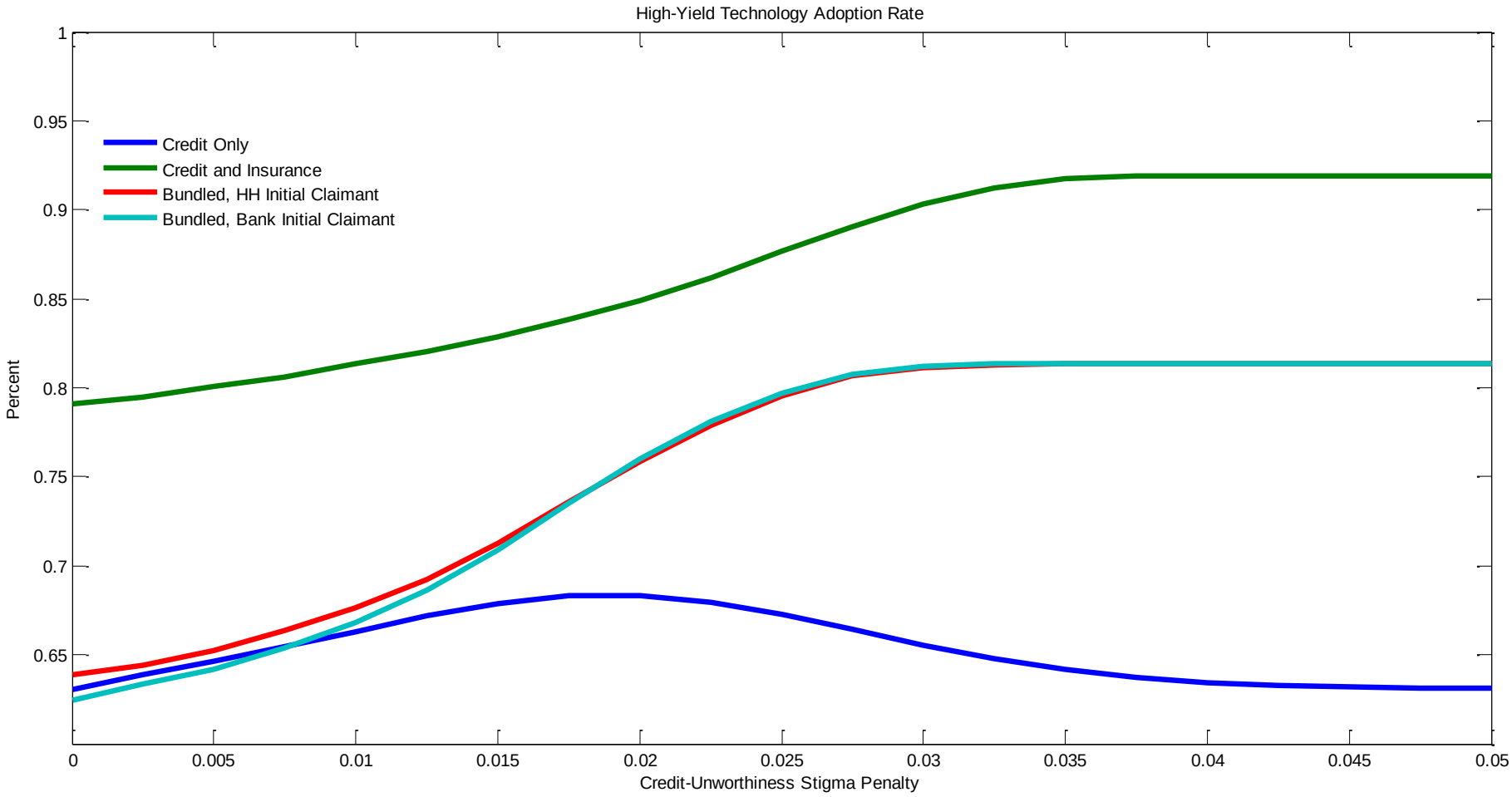
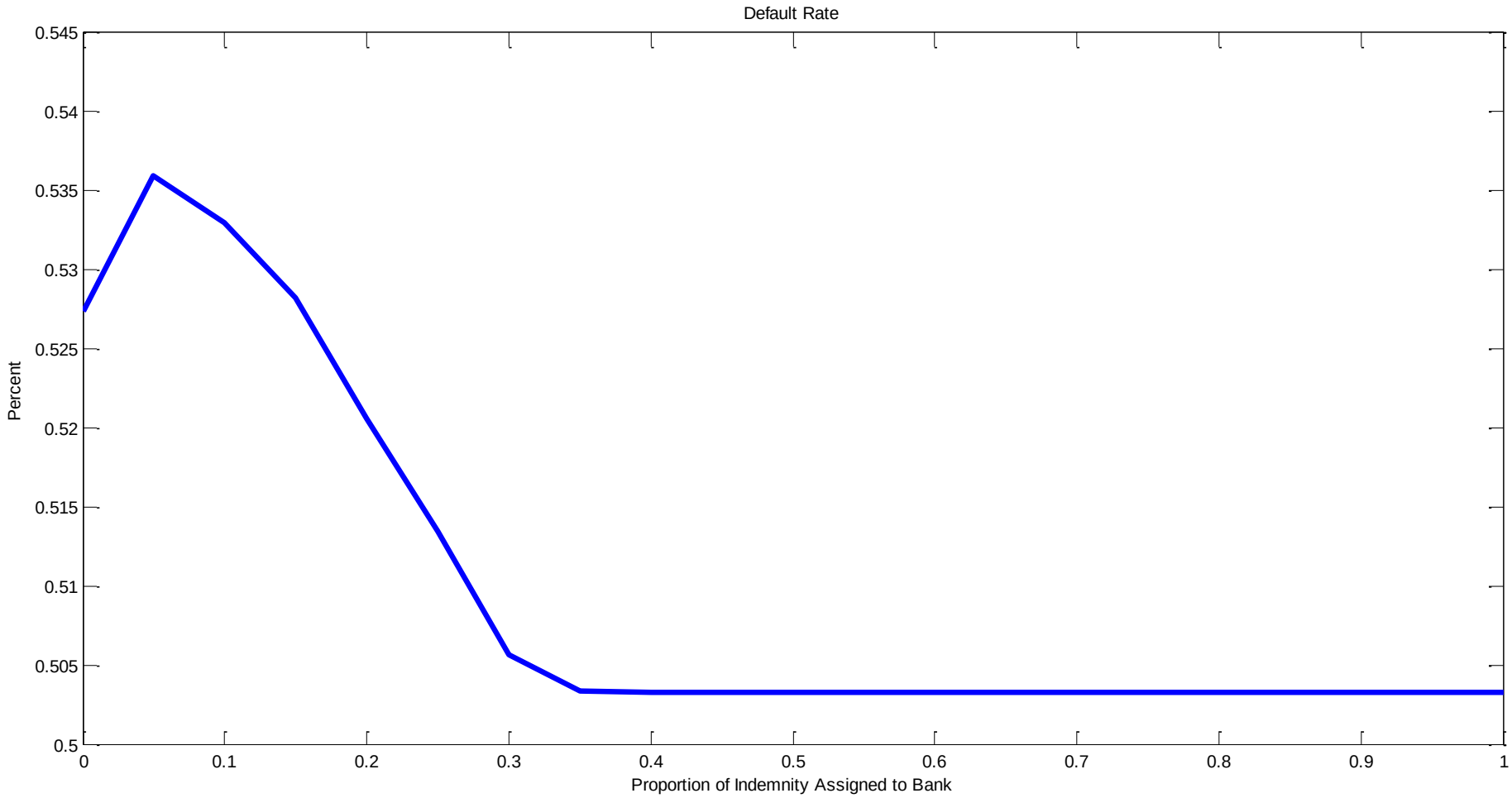

High-Yield Technology Adoption Rate
Credit Only
Credit and Insurance
Bundled, HH Initial Claimant
Bundled, Bank Initial Claimant
Percent
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045
0.05
Credit-Unworthiness Stigma Penalty

Figure 10


Default Rate
Percent
0.545
0.54
0.535
0.53
0.525
0.52
0.515
0.51
0.505
0.5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Proportion of Indemnity Assigned to Bank