Unlocking Access to Credit with Lockout Technology*

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Abstract

A new form of collateralized lending has emerged, most prominently in developing countries, that is facilitated by a "lockout" technology, which allows the lender to temporarily disable the flow value of the collateral to the borrower without physically repossessing it. We explore the effect of this new technology both in a model and in a randomized controlled trial using school-fee loans collateralized with a solar home system. We find that securing a loan with lockout drastically reduces default rates (by 15 pp) and increases the lender's rate of return (by 5 pp per month). Employing a variant of the Karlan and Zinman (2009) methodology, we decompose the total effect and find that roughly one-third of the total effect is attributable to (ex-ante) adverse selection and two-thirds of the effect is attributable to (ex-post) moral hazard. Access to a school-fee loan significantly increases school enrollment and school-related expenditures without detrimental effects to household's balance sheet.

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1 Introduction

There is a general consensus that households in poor countries have insufficient access to credit. Twenty years ago, economists were optimistic that microfinance would fill this void. However, most of the evidence suggests that microfinance loans do not have transformative effects on the average borrower Banerjee et al. (2015).

Traditional microfinance loans are characterized by high interest rates, large transaction costs, and low uptake. They are also unsecured. In contrast, most household debt is secured by collateral in rich countries. In the US, more than 80% of total household debt is secured by a physical asset (either a mortgage or auto loan).[1] Using collateral to secure debt helps overcome economic frictions thereby expanding the supply of credit and/or reducing the cost of credit provision. Yet, secured debt is much less prevalent in very poor countries. Why? In economies with weak legal enforcement, property rights are difficult to establish, which translates to a high cost of repossessing collateral for creditors. This is especially true for households in remote areas, where the costs associated with locating the asset and physical repossessing it are prohibitive.

We argue that collateral need not be physically repossessed in order to serve a useful role in the provision of credit. Provided the creditor can disable the benefits of the asset to the borrower, it can serve as a useful role. A leading example is pay-as-you-go financing (PAYGO), which has emerged as a common financial contract for the sale of solar home systems (SHSs) in the developing world and as a way to finance the purchase of smartphones. The typical PAYGO contract requires a nominal down payment to take possession of the product, followed by frequent small payments made via a mobile payment system to unlock the product for some amount of time or usage. PAYGO financing crucially relies on an embedded "lockout technology" that allows the seller to remotely, cheaply, and temporarily make the product unusable. Notably, the collateral can be "re-used" for additional loans once the borrower has paid off the initial loan.

In this paper, we will explore this new form of collateralized lending within a stylized model and then in a randomized control trial. In the model, firms produce a good that is of

[1]Source: "Quarterly Report on Household Debt and Credit," Federal Reserve of the Bank of New York (2020), https://www.newyorkfed.org/medialibrary/interactives/householdcredit/data/pdf/HHDC_2020Q2.pdf.

value to households. Households have a private value of consuming the good that is realized after they take possession of it. They are also subject to unobservable income shocks. Due to their financial constraints and limited wealth, households cannot afford to purchase the good outright. Therefore, in order to recoup their costs, firms offer a loan contract that is collateralized by the good: if the household does not repay the loan then the firm repossess the good.

Repossessing collateral can serve two roles in the model: (1) it provides the firm with something of value should the household default, and (2) it provides incentives to the household to repay the loan in order to avoid repossession. Collateralized lending via lockout involves zero recovery value for firms when households default, and yet still provides strong incentives to households to repay the loan. Relative to to an unsecured loan, a loan collateralized with lockout can reduce lending costs via two channels. First, the technology reduces moral hazard (i.e., strategic default) compared to an unsecured loan. Thereby, for the same borrower, we anticipate higher repayment rates when the lockout is employed. Second, lockout serves as a useful screening mechanism to overcome adverse selection. That is, a borrower that is more likely to face a negative income shock will have less incentive to accept a loan collateralized with lockout. By reducing strategic defaults and adverse selection, lenders can offer loans to creditworthy borrowers at interest rates they find acceptable. In spite of the two (aforementioned) attributes, a stronger lockout technology does not necessarily increase welfare. The reason is that stronger lockout leads to more surplus destruction when it is employed, which can offset the gains of the credit expansion.

We test the predictions of the model and measure the effects of access to a collateralized loan in a field experiment. To conduct the experiment, we partnered with Fenix International, the largest solar-home system provider in Uganda. Our study examines the effects of lockout with Fenix's most popular follow-up product, a school-fee loan that is offered to customers near the beginning of each school term. Specifically, we are interested in (1) the effect of lockout on loan take-up, repayment, and default, (2) the decomposition of the total effect on repayment into moral hazard and adverse selection, (3) the impact of a loan on educational outcomes, and (4) the impact of the loan on households' other economic and financial variables. Our experimental design randomizes the sample into 3 treatment groups

and a control group. In the first treatment, the customer is offered a loan that utilizes the lockout technology. The second treatment is a loan without the lockout technology enabled (i.e., an "unlocked" loan). In the third treatment, a customer is offered a lockout loan, but if the customer accepts the loan, he or she is (positively) "surprised" and receives an unlocked loan. The "surprise" unlocked group is used to identify the effect of adverse selection from moral hazard a la Karlan and Zinman (2009).

Our experiment yields four main results. First, customer interest and take-up rates are reasonably high. More than 12% of the over 27,000 customers who received an SMS about the loan indicated they were interested. Of the 2,200 customers that were offered a loan, 49% took-up the offer and received a loan. Consistent with our hypothesis that lockout reduces adverse selection, the take-up rate was about 7 percentage points (pp) higher for customers offered an unlocked loan than those offered a locked loan (47% vs 40%).

Second, lockout significantly increases loan repayment. The average repayment rate (fraction of principal repaid) increased by 12 pp when the loan was collateralized with lockout compared to being unsecured. Lockout decreased the default rate by 15 pp. From a profitability standpoint, lockout increased the (annualized) internal rate of return on school-fee loans by 60 percentage points. About one-third of the total effect can be attributed to adverse selection while two-thirds is driven by moral hazard. The reduction in moral hazard effects was concentrated among higher risk borrowers (based on repayment of previous loans) whereas the reduction in adverse selection was concentrated among lower risk borrowers. Consistent with our theoretical framework, households with a higher willingness to pay for the service flow from the SHS system were less likely to take-up a loan with lockout.

Third, the school-fee loan had positive impact on both enrollment and school expenditures. Children in households that were offered a school-fee loan were significantly more likely to be enrolled at school compared to children in the control group. Accounting for loan take up, our results suggest that the loans cut the share of children who were not enrolled by half (from 12% to 6%). In addition, households with loans increased schooling related expenditures by 36%. Increases in enrollment were concentrated among males. Increases in expenditures were concentrated on females, although this last result is not statistically significant.

Fourth, the loans did not have significant effects on household balance sheets. Asset purchases (sales) increased (decreased) moderately, but not significantly, and household borrowing was largely unchanged. Our estimates are precise enough to rule out large negative impacts.

On net, our results suggest that lockout increases the share of customers to whom a company can profitably offer loans. And, these loans had significant impact on household decisions around schooling, suggesting that the customers did not have access to other sources of credit for an important expenditures like school fees.

While our results are mostly positive, using lockout technology to collateralize loans is not without cost. First, there are costs associated with integrating and installing the lockout technology into a solar-home system. Second, there is an (ex-post) inefficiency associated with locking devices. Lockout enabled SHS are locked approximately 15-20% of their useful life. On one hand, this could be viewed as a feature of the PAYGO/lockout contract; customers need not make payments on days in which they do not require (or have a low value) for electricity. (In contrast, borrowers face permanent repossession if they fail to repay more traditional secured debt.) On the other hand, it suggests that there is potential room for improvement in the contract design (e.g., when lockout is utilized).

While our study focuses on solar-home systems, there are other existing applications of the lockout technology. For example, PayJoy, a FinTech firm based in San Francisco, provides financing for smartphones enabled with lockout. PayJoy has been offering credit for the purchase of smart phones since 2016 and has a new product that offers loans to customers who have completed the phone loan repayment. They have large scale operations in Mexico, and a small but growing customer base in South Africa, India, Indonesia, and Zambia.

A similar technology has been deployed in the United States for subprime auto loans. Several firms have developed starter interrupt devices, which allow the lender to remotely disable the ability to start the car if the borrower is not in good standing on the loan. According to an article in the NY Times, these devices have been installed in more than two million vehicles.[2] With the proliferation of smart devices, the PAYGO model could

[2]See https://dealbook.nytimes.com/2014/09/24/miss-a-payment-good-luck-moving-that-car.

easily be extended to a wide range of devices such as laptops, refrigerators, and televisions. And importantly, the capacity to reuse collateral for future loans (as it has been by Fenix) expands the potential impact of the innovation as a vehicle for affordable access to credit.

2 Related Literature

Our paper relates to several different literatures including the use of collateral in credit markets, microfinance and education in development economics, and rural electrification.

2.1 Collateral in Credit Markets

There is a large theoretical literature explaining the use of collateral in credit markets. Most relevant to our work are the numerous papers that have illustrated how collateral can be useful to mitigate inefficiencies associated with moral hazard, adverse selection, and limited enforcement. In a model with adverse selection, Bester (1985) shows that the credit rationing in Stiglitz and Weiss (1981) can be (partially) overcome through the use of collateral as a screening device: better credit risks post more collateral and receive a lower interest rate, thereby eliminating the need for rationing. Of course, securing debt with collateral does not come without cost: indeed, by assumption, posting collateral is more costly for riskier borrowers leading to a single-crossing property that facilitates screening. Related models with adverse selection obtain similar findings (Chan and Kanatas, 1985; Bester, 1987; Besanko and Thakor, 1987a,b). Another explanation for the use of collateral is to alleviate moral hazard problems: posting collateral makes it more costly for a borrower to risk shift or shirk (Bester, 1987; Chan and Thakor, 1987). Posting collateral also makes it more costly for borrowers to strategically default, and therefore can be used to make up for a lack of pledgeable income (Tirole, 2006, p.169).[3]

There is also an extensive empirical literature on the role of collateral in credit markets. Consisting with our findings, a number of papers have found evidence consistent with moral

[3]The theoretical literature also illustrates other roles for the use of collateral (or control rights) including incomplete contracts ((Aghion and Bolton, 1992; Hart and Moore, 1994)), monitoring incentives (Rajan and Winton, 1995), priority (Ayotte and Bolton, 2011), limited enforcement (Rampini and Viswanathan, 2013), exclusivity (Donaldson et al., 2019), and as a commitment device (DeMarzo, 2019).

hazard ((Berger and Udell, 1990, 1995; Jimenez et al., 2006)). Three other important and relevant points emerge from this literature.

First, the potential economic benefits of collateral are more significant in poorer countries and countries with weaker creditor rights protection. Liberti and Mian (2010) finds that the collateral spread between high-risk and low-risk borrowers is greater in countries with weaker creditor rights protection or worse information sharing institutions, suggesting a greater reliance on collateral in these countries. Benmelech et al. (2020) argues that one reason secured debt was more prevalent among US firms in early twentieth century than later is that the accounting standards and creditor rights protection were less developed earlier, giving greater necessity for collateral.

Second, there is ample evidence that a more efficient repossession technology leads to an expansion of credit and lower borrowing costs. One source of inefficiency is the transaction and liquidation costs involved after repossession. Assunção et al. (2013) shows that loan spreads dropped and credit expanded in Brazil after a reform that simplified the sale of repossessed cars used as collateral for auto loans. Benmelech and Bergman (2009) finds that debts secured by more redeployable collateral exhibit lower credit spreads, higher credit ratings, and higher loan-to-value ratios. Another source of inefficiency are the costs associated with repossessing collateral after default due to weak creditor rights. In countries with stronger creditor rights protection (and thus lower costs of repossession), the credit markets are more developed and this may contribute to economic growth (e.g., La Porta et al. (1998); Qian and Strahan (2007); Djankov et al. (2007)). Ponticelli and Alencar (2016) explores variations across Brazilian municipalities and arrives at a similar conclusion. Mann (2018) also supports this view. However, Vig (2013) offers contrasting evidence from a natural experiment: stronger creditor rights can lead to a decrease in the use of secured debt (e.g., if the contracting space is limited). Expanding the set of assets that can be used as collateral can also be viewed as an improvement in the efficiency of the repossession technology. Loumioti (2012) and Benmelech et al. (2020) document an increase in use of intangible assets as collateral in recent years. Mann (2018) finds that both debt capacity and R&D expenditure of patenting firms increased after court decisions that strengthened creditor rights to patents.

Third, borrowing secured is not without cost. Exhausting pledgeable assets may mean

losing financial flexibility and giving up profitable future investment opportunities (see, e.g., (Acharya et al., 2007; Rampini and Viswanathan, 2010, 2013; Li et al., 2016; Donaldson et al., 2019)). By pledging collateral, a firm also limits its flexibility to sell or redeploy assets to craft a better business operation. Indeed, Benmelech et al. (2020) document a significant decline in secured debt (as a fraction of total debt) among US firms over the twentieth century attributed in part to these reasons. Acharya et al. (2011) also points out that the adverse consequence of default and repossession of collateral can induce managers to take risks below the optimal level.

2.2 Education in Developing Countries

Out-of-pocket costs are an important constraint to education in most African countries, as families are asked to pay for things like school fees, books and supplies, lunch, uniforms and transport (Williams et al., 2015). In Uganda, the median household spends 17% of income on primary education (conditional on reporting primary education spending) and 27% of income on secondary education (conditional on reporting secondary education spending). Both figures are from the 2019 Living Standards Measurement Survey.

A number of recent studies estimate the impact of reducing those costs on educational outcomes. İşcan et al. (2015) use regression analysis to show that the introduction of school fees reduced enrollment and subsequent completion of primary school across seven African countries. Moussa and Omoeva (2020) use a fuzzy regression discontinuity design to examine the impact of universal primary education policies in Ethiopia, Malawi, and Uganda: they find an increase in educational attainment. In Kenya, free primary education—rolled out in 2003—increased educational attainment (Ajayi and Ross, 2020). Free basic education increased girls' attainment in Ghana and Uganda (Adu Boahen and Yamauchi, 2017; Masuda and Yamauchi, 2018). The elimination of primary school fees in Ethiopia led to more schooling for both men and women (Chicoine, 2019, 2020). In Tanzania, free primary education increased enrollment (Delesalle, 2019; Valente, 2019). Lesotho also saw dramatic gains in access with the elimination of fees (Moshoeshoe et al., 2019). In the Gambia, eliminating secondary school fees for girls increased the number of girls taking the high school exit exam by more than 50 percent. Finally, a randomized controlled trial of scholarships for

students in Ghana who had already passed the entrance exam but lacked financing increased secondary and tertiary attainment (Duflo et al., 2019).

Conditional and unconditional cash transfer programs are a primary policy that many governments use to help households overcome financial barriers to schooling. Conditional cash transfers function much like school scholarships. While many of the early studies of conditional cash transfer programs were from Latin America and the Caribbean (Fiszbein et al., 2009), early evidence from Africa showed promising results in that setting as well (Davis et al., 2016). In Malawi, unconditional cash transfers showed an increase in school enrollment and reduced dropout rates (Kilburn et al., 2017). In Kenya, unconditional transfers did not translate to improved educational outcomes after nine months (Haushofer and Shapiro, 2016). Baird et al. (2014) compare conditional cash transfers for already enrolled and un-enrolled adolescent girls in Malawi: they find enrollment gains for both groups and mixed effects on test scores. An unconditional cash transfer program in Rwanda increased educational investments (more children had school uniforms) but did not affect school attendance (Sabates et al., 2019).

Loans are not a common mechanism for financing K-12 schooling in most low- and middle-income countries. However, loans are common in some countries for tertiary education. Solis (2017) estimates the causal impact of loan access on college enrollment using Chilean data and a discontinuity in eligibility for subsidized student loans and finds that access to student loans eliminate the large gap in enrollment rates between students from different family income quintiles: access to student loans results in a 100% increase in probability of college enrollment relative to the group with test scores just below the eligibility threshold. Gains are largest for students from the lowest family income quintile: access to loans leads to a 140% increase in the probability of immediate enrollment, relative to a 15% baseline enrollment rate just below the cutoff. Gurgand et al. (2011) exploit the eligibility threshold of a South African program that provides short- and medium-term loans (12-24 months) to cover university tuition for middle to upper-middle income household who are not eligible to means-tested state loans, and have a high credit score. Despite these not being very good loans – they are not subsidized and need to be repaid while studying, they require a guarantor or a monthly salary at least 4 times the size of the installments – Gurgand et al.

(2011) find that access to them increases enrollment 20-25 percentage points, equivalent to 50% of baseline enrollment.

The literature on the effects of graduating with debt is quite recent and mostly from the US. Cai et al. (2019) show that students have trouble repaying mortgage-style loans in China and Dearden (2019) finds similar results in Brazil. In the US, Mezza et al. (2016) instrument student debt changes with the in-state tuition rates at public 4-year colleges in the student's home state. They find that a $1,000 increase in student debt lowers the home-ownership rate of individuals who attended public 4-year colleges by about 1.5 percentage points during their mid-20s, equivalent to a 2.5-month delay. Graduating with debt affects the future careers of students: students who graduate with debt are more likely to take jobs with higher wages and lower job satisfaction (Minicozzi, 2005; Rothstein and Rouse, 2011; Chapman and Lounkaew, 2015; Xu, 2017). These studies all focus on debt for tertiary education, however, so it is unclear how the results translate to debt for primary or secondary education.

2.3 Rural Electrification

This paper is also related to the literature on rural electrification (see Lee et al. 2020 and Blimpo and Cosgrove-Davies (2019) for recent overviews). In general, the results from that literature suggest that the impacts of electrification are moderate at best, including for small solar home systems, such as the devices Fenix sells. However, this literature primarily considers outcomes more traditionally associated with electricity, such as those related to increased access to a clean and reliable lighting source. The fact that a small solar home system can be used as collateral on a loan is not something that the literature has considered. A crucial aspect of the lockout technology that we study is that it can be enabled remotely, which requires some form of digital communication. So, access to modern telecommunications and electricity infrastructures are essential to lockout.

3 A Model of Lockout

In this section, we propose a stylized model of collateralized lending in order to illustrate three main points. Our framework is similar in spirit to the work of Bester (1985, 1987) and Besanko and Thakor (1987a). Our primary contribution is to decompose the repossession technology into two independent parameters in order to isolate and understand the role of lockout.

Our main findings are as follows. First, lockout increases borrowers repayment incentives thereby the reducing the moral hazard problem. Second, lockout leads to *positive* selection i.e., borrowers with sufficiently high (ex-ante) income risk will be unwilling to accept a loan collateralized by lockout. In combination, these finding imply that the lockout technology makes it easier for firms to recover productions costs and increase the supply of credit. Our third point is more subtle. Despite the two (aforementioned) attributes, a stronger lockout technology does not necessarily increase welfare. The reason is that stronger lockout leads to more surplus destruction when it is employed, which can offsets the gains of mitigating the economic frictions.

The model has two dates (date 0 and date 1) and two types of agents (households and firms). Households would like to purchase a durable good produced by firms, but have limited wealth. Firms produce the good and can also provide financing for it. However, due to incomplete markets (e.g., moral hazard, adverse selection), firms require collateral in order underwrite household debt.

Households. There is a unit mass of households, indexed by $i \in [0, 1]$. Household i derives (random) utility from consuming the production good at date 1, denoted by $\tilde{v}_i$, which is distributed according to F on support $[\underline{v}, \bar{v}] \in \mathbb{R}$. Household i privately observes $\tilde{v}_i$ at the beginning of date 1.[4]

Each household has date-1 income denoted by $\tilde{y}_i$. Households are heterogeneous with respect to income risk: with probability q_i, household i experiences an income shock and $\tilde{y}_i = 0$. With the complimentary probability, household i has sufficient income, $\tilde{y}_i = y > \bar{v}$,

[4]A higher realization of $\tilde{v}_i$ can be interpreted either as deriving from a shock leading to a particularly high value for consuming the good or from a positive income shock and thus a lower marginal utility from consumption of other goods.

but may still choose to strategically default. Thus, higher q_i correspond to riskier households. Without out loss, assume that q_i is increasing in i. Households know their risk type. Let G and g denote the distribution and density of risk types in the population, which has support $[0, \bar{q}]$. For simplicity, we assume that all households have the same wealth $w_i = w$ for all i and that households are risk-neutral utility maximizers with a discount factor normalized to 1.[5]

Firms. There are $N \geq 1$ identical firms. Each firm has the technology to produce a good that generates value for households at date 1. Each firm has a marginal production cost c. Firms have deep pockets so they have the ability to provide financing to their customers. At the beginning of date 0, firms first decide whether to enter (pay c to produce the good). Conditional on entry, firms design a contract, which is a pair (d, p), where d is the downpayment required at date 0 to take possession of the good and p is the price of consuming the good at date 1. If a household takes possession at date 0, but does not make the payment at date 1, then the firm "repossesses" the good.[6]

Repossession. Repossessing the good has two implications

1. *Recovery.* It provides the firm with something of value should the borrower fail to repay.

2. *Incentives.* It takes something of value away from households should they fail to repay.

In most models of collateralized lending, these two roles are inseparable and characterized by a single parameter (e.g., Kiyotaki and Moore (1997)). The lockout technology facilitates a decoupling of the two roles. This decoupling can be useful when the cost of recovery outweighs the recovery value.

[5]Risk-neutrality simplifies the space of relevant contracts since there is no demand for intra- nor inter-temporal consumption smoothing.

[6]We take the form of contract as given because it is representative of what is used in practice by PAYGO providers and in our experiment. If households are identical (e.g., $q_i = q$ for all i) or risk is observable, then, under the Myerson's (1981) regularity condition, this contract is optimal within a more general class of mechanisms in which the date-1 transfer and repossession are contingent on the household's reported value. With heterogenous households and unobservable risk, it can be optimal to offer a menu of contracts.

To separate the two roles, we parameterize firms repossession technology by the pair (κ, λ), where κ denotes the effectiveness of recovery—it is the fraction of the production cost that the firm recovers from repossession, and λ denotes the effectiveness on incentives—the borrower enjoys only the fraction $1 - \lambda$ times her value of the good in repossession.[7]

As discussed earlier, physical repossession is prohibitively costly in economies with weak creditor rights and limited enforcement. Therefore, a (traditional) collateralized loan, where the asset is physically repossessed in default, is characterized by relatively low values of both κ and λ. A loan collateralized with lockout involves no physical repossession in default (i.e., $\kappa = 0$), but also little to no value for customers who default (i.e., λ close to 1). Our primary interest will be to explore how an improvement in the lockout technology (i.e., increasing λ) affects household incentives and the equilibrium outcome.

To fix ideas, we will make the following parametric assumptions.

Assumption 1 (Trade is ex-ante efficient) $\mathbb{E}[\tilde{v}_i] > c$.

Assumption 2 (Repossession is inefficient ex-post) $\lambda v > \kappa c$ *for all* $v \in [\underline{v}, \bar{v}]$.

Given these assumptions, the first-best outcome is for all households to purchase the good and for firms to never repossess the good. This outcome can be sustained as an equilibrium even without lockout if households have sufficient wealth. Assumption 3 rules out this possibility.

Assumption 3 (Households are financially constrained) $w < c - \underline{v}$, *but households that do not experience a shock have enough wealth and income to afford the good:* $w + y > c$.

Finally, we impose the Myerson (1981) regularity assumption on the distribution of household values, which is commonly used in auction theory in mechanism design.

Assumption 4 (Monotone virtual surplus) $v - \frac{1-F(v)}{f(v)}$ *is monotonically increasing in* v.

[7] One can interpret λ as the probability with which the good is successfully repossessed from the borrower and $(1 - \kappa)/\lambda$ as the rate of depreciation or the cost of repossession the good (as a fraction of c).

3.1 Household Behavior

We begin by considering the behavior of households taking the contract (d, p) as given. Suppose that household i purchases the good at date 0. The household will repay at date 1 provided that (i) it does not experience an income shock (i.e., $y_i = y$), and (ii) $\tilde{v}_i - p \geq (1-\lambda)\tilde{v}_i$, or equivalently

$$\tilde{v}_i \geq \frac{p}{\lambda} \tag{1}$$

The right hand side is decreasing in λ, meaning that a more effective lockout technology leads to a higher probability of repayment, thereby illustrating the incentive role of repossesion.

Proposition 1 (Lockout Reduces Moral Hazard) *Fixing a contract, a more effective lockout technology (i.e., higher λ) decreases the probability that household i strategically defaults.*

Consider now the purchase decision of households. The expected date-1 surplus to household i is given by

$$S_i(p) \equiv (1-q_i)\left[\int_{\underline{v}}^{\bar{v}} \max\{v-p, (1-\lambda)v\} dF(v)\right] + q_i(1-\lambda)\mathbb{E}(\tilde{v}_i)$$

Household i will purchase the good if they can afford to do so and the surplus from purchasing is non-negative. More concisely, household i will purchase the good if

$$d \leq \min\{w, S_i(p)\}. \tag{2}$$

Let $U_i(d, p) = S_i(p) - d$ denote household i's expected utility from purchasing the good. When facing a menu of contracts, household i selects contract the contract that maximizes expected utility provided that it satisfies (2). Otherwise, the household does not purchase the good. Noting that $S_i(p)$ is decreasing in both q_i and λ, we have the following result.

Proposition 2 (Lockout Reduces Adverse Selection) *Fixing a contract, there exists $\underline{q}$ such that only households with income risk $q_i \leq \underline{q}$ choose to purchase. Moreover, $\underline{q}$ is*

decreasing in λ.[8]

This results shows that lockout leads to *positive selection*. Households with more credit risk prefer not to purchase the good because they anticipate a higher chance of being locked out.

3.2 Firm Profits

The lowest utility type that strategically defaults when the price is p is

$$v(p) = \begin{cases} \underline{v} & p \leq \lambda \underline{v} \\ p/\lambda & p \in (\lambda \underline{v}, \lambda \bar{v}) \\ \bar{v} & p \geq \lambda \bar{v} \end{cases} \tag{3}$$

For any p, the probability that household i repays is $(1 - q_i)(1 - F(v(p)))$ and a firms expected revenue at date-1 from selling to household i is

$$R_i(p) = \kappa c + (1 - q_i)(1 - F(v(p)))(p - \kappa c)$$

Date-1 revenue is increasing in both κ and λ and decreasing in q_i. The profit from selling to household i is

$$\pi_i(d, p) = \begin{cases} d + R_i(p) - c & \text{if } d \leq \min\{w, S_i(p)\} \\ 0 & \text{otherwise} \end{cases} \tag{4}$$

Because it will play a role in the equilibrium analysis, consider the problem of maximizing date-1 revenue with respect to the lowest type the strategically defaults, v. The marginal revenue to the firm of increasing v for household i is

$$(1 - q_i)\left[(1 - F(v))\lambda - f(v)(\lambda v - \kappa c)\right].$$

[8]Proposition 2 can be strengthened if $S_1(p) < d \leq w < S_0(p)$, which is necessary and sufficient to guarantee that some but not all households purchase the good (i.e., $\underline{q} \in (0, 1)$). In this case, $\underline{q}$ is *strictly* decreasing in λ.

The first order condition for an interior solution is

$$v^* - \frac{1 - F(v^*)}{f(v^*)} = \frac{\kappa c}{\lambda}, \tag{5}$$

which has a unique solution by Assumption 4. Notice that v^* is independent of q_i, and increases with κ, but decreases with λ. Higher κ or higher λ both correspond to a "better" repossession technology, but they have different effects on the marginal household type who strategically defaults; higher κ gives the firm more incentive to repossess which always increases v^*, whereas higher λ decreases v^*.

As we will see shortly, the solution to (5) is intimately linked to the pricing decisions of firms. In particular, when households financial constraints are severe, then the equilibrium price is $p^* = \lambda v^*$. We therefore have the following comparative static result.

Proposition 3 (Recovery vs Incentives) *When households are sufficiently constrained (i.e., for w small enough):*

- *Increasing κ (more efficient recovery) leads to more strategic default and repossession.*
- *Increasing λ (stronger lockout) leads to fewer strategic defaults and less repossession.*

3.3 Equilibrium

The equilibrium will naturally depend both on the degree of competition among firms as well as whether firms can observe households' risk type. In this section, we consider the case with observable household risk type. It is perhaps the most relevant case for our experiment; Fenix obtains a significant amount of repayment data on their existing customers prior to offering them additional loans and uses repayment history to determine eligibility. When firm's can observe household risk types, they will tailor the pricing of the contract to the household as well as screen households with too much income risk.

3.3.1 Single Firm

When the firm is a monopolist, it will offer the contract that maximizes the profit from selling to household i. That is, the contract offered to household i solves

$$(d_i, p_i) \in \arg\max_{d,p} \pi_i(d, p)$$

We can decompose the problem into two steps. First, maximize profit conditional on selling to household i. Then decide whether to sell to household i.

Clearly, the firm's profit is increasing in d. So, conditional on selling, it will be optimal to set $d_i = \min\{w, S_i(p)\}$. Thus, the firm's problem can be written as

$$\max_p \left(\min\{w, S_i(p)\} + R_i(p) - c\right)$$

When $w \leq S_i(p^*)$, the solution is to set $p_i = p^*$ and charge $d_i = w$. This leaves the household with surplus $S_i(p^*) - w \geq 0$. When $w > S_i(p^*)$, the household will be unwilling to purchase at these terms. In order to induce the household to purchase, the firm charges less than p^* at date 1. In particular, by setting the price such that $S_i(p) = w$ and charging a downpayment $d = w$.[9] The following lemma summarizes these finding.

Lemma 1 (Monopoly Prices) *Conditional on selling to household i, the solution to the monopolist problem involves $d_i = w$ and*

$$p_i^m = \begin{cases} p^* & \text{if } w \leq S_i(p^*) \\ S_i^{-1}(w) & \text{otherwise} \end{cases}$$

If the implied profit from the contract in Lemma 1 is positive, then it is optimal for the firm to sell to household i. Otherwise, the household will reject any offers that the firm is willing to make.

Proposition 4 (Monopoly Quantities) *With observable household risk, the monopolist will sell to household i if and only if either*

[9] Assumption 3 ensures that it will not be profitable to sell to any household i at $p_i = 0$.

(i) $w + R_i(p^*) \geq c$ *when* $S_i(p^*) \geq w$, *or*

(ii) $w + R_i(S_i^{-1}(w)) \geq c$ *otherwise.*

Noting that both R_i and S_i are decreasing in q_i, we have the immediate following corollary.

Corollary 1 *For any* $\lambda > 0$, *there exists* q^* *such that only households with* $q_i < q^*$ *will purchase the good.*

Since the downpayment is simply a transfer, we can ignore it when computing total suplus. The total surplus in the economy is given by

$$TS = \int_0^{q^*} (R_i(p_i) + S_i(p_i) - c) dG(q_i).$$

Total firm profit and consumer suruplus are given by $\Pi = \int_0^{q^*} \pi_i(d_i, p_i) dG(q_i)$ and $CS = \int_0^{q^*} U_i(d_i, p_i) dG(q_i)$.

3.3.2 Competitive Firms

When firms compete for households, they offer the contract that maximizes each households welfare subject to breaking even. That is, the contract offered to household i solves

$$(d_i, p_i) \in \arg\max_{d,p} U_i(d, p)$$
$$s.t. \quad \pi_i(d, p) = 0$$

Household expected utility is decreasing in both d and p. However, the deposit is purely a transfer while a higher p destroys more surplus. Therefore, to maximize household utility, firms minimize p_i subject to breaking even.

Proposition 5 (Competitive Equilibrium) *In a competitive equilibrium with observable household risk, the following are true:*

1. *The household purchases the good if and only if condition (i) or (ii) from Proposition 4 is satisfied. Otherwise, there does not exist a contract such that both the firm breaks even and the household is willing to purchase.*

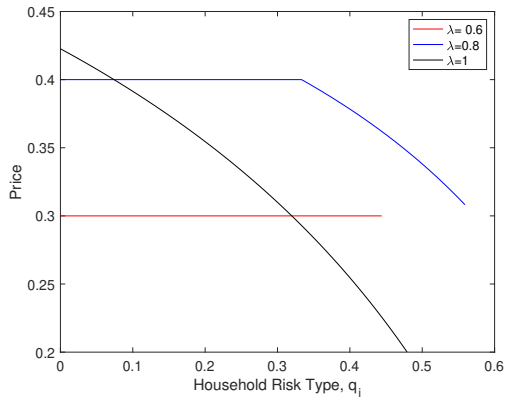


Figure 1: Monopoly prices, p_i^m. All households who purchase the good face a downpayment equal to their wealth: (i.e., $d_i^m = w$).

2. *If the household purchases the good then* $d_i^c = w$ *and* p_i^c *is the lowest price such that* $R_i(p_i^c) = c - w$.

Notice that the household purchases under the exact same conditions as when the firm is a monopolist. Thus, Corollary 1 also holds with competitive firms. Of course, the price offered by competitive firms is lower for all but the marginal household.

3.4 Parametric Example

Suppose that $\tilde{v}_i \sim U[0,1]$, $q_i \sim U[0,1]$, $\kappa = 0$, $c = \frac{1}{4}$. Then $v^* = \frac{1}{2}$, $p^* = \frac{\lambda}{2}$, and

$$R_i(p^*) = \frac{1}{4}\lambda(1 - q_i),$$

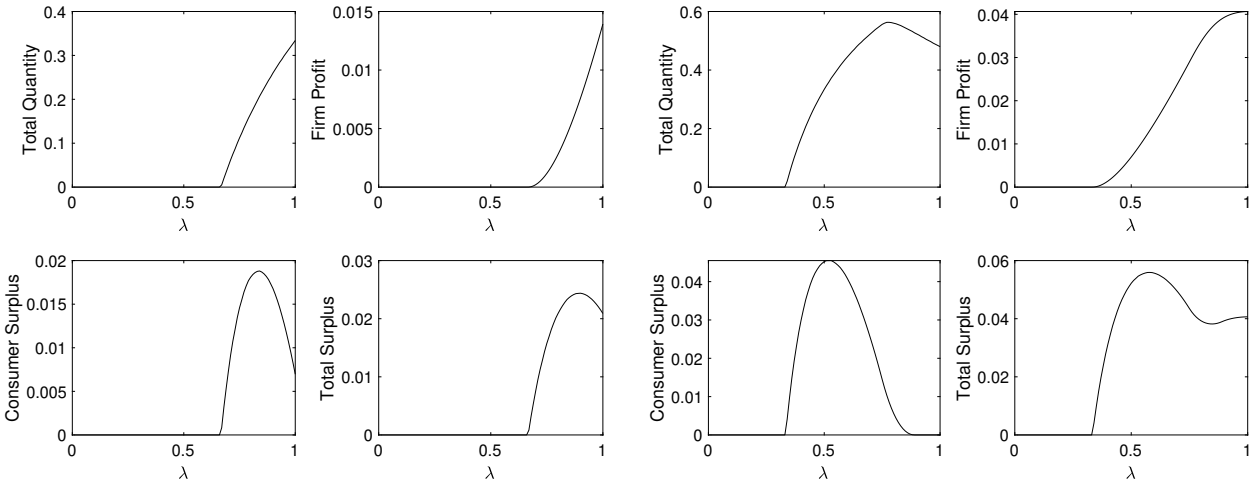
$$S_i(p^*) = \frac{1}{2} - \frac{\lambda(3 + q_i)}{8}.$$

There are two possible cases depending on λ relative to $c - w$.

(i) For $\lambda < 4(c - w)$, then $q^* = 0$ meaning that no households purchase.

(ii) For $\lambda \geq 4(c - w)$, $q^* = 1 - \frac{4(c-w)}{\lambda}$ and the mass of households that purchase is $G(q^*) = 1 - \frac{4(c-w)}{\lambda}$.

Figure 1 illustrates the solution to the monopolist's problem as it depends on both household risk type as well as λ. For $\lambda = 0.6$, the firm sells only to households with $q_i \leq 0.45$ and



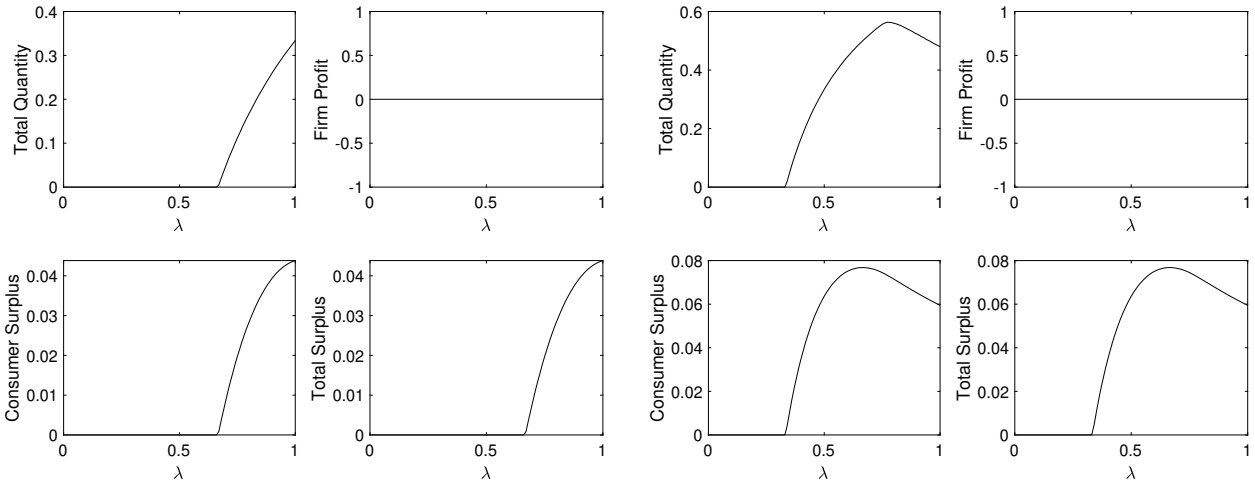
(a) Low household wealth, $w = \frac{1}{12}$.

(b) High household wealth, $w = \frac{1}{6}$.

Figure 2: Illustrating the role of lockout with a monopolist firm.

all household who purchase the good get the same price p^*. For $\lambda = 0.8$, the firm sells to more households and (mostly) at higher prices; households with $q_i < 0.33$ face a price of p^*, those with intermediate income risk ($q_i \in (0.33, 0.58)$) are unwilling to purchase at p^*, but are still profitable so the firm sells to them at $S_i^{-1}(w)$. For $\lambda = 1$, even more households are profitable under the contract (w, p^*), but none of them are unwilling to purchase at those terms. Therefore, the firm has to charge a price less than p^* to all customers in order to induce them to purchase. As a result, the profitability of each customers falls and fewer households end up being served (i.e, q^* falls).

Quantity and profit is increasing in λ as illustrated in the top panels of Figure 2. Household welfare increases with λ on the extensive margin ($q_i = q^*$) as more households get served. However, households that were already purchasing the good ($q_i < q^*$) face higher date-1 prices. As a result, aggregate household welfare can decrease with λ. This possibility is clearly illustrated in Figure 2(b), where both household and total surplus decreases for λ large enough. Intuitively, a stronger lockout technology increases the incentive to repay, but also destroys more value when the household defaults. This effect is most pronounced on households with more higher income risk as they are more likely to default for non-strategic reasons.



(a) Low household wealth, $w = \frac{1}{12}$.

(b) High household wealth, $w = \frac{1}{6}$.

Figure 3: Illustrating the role of lockout with competitive firms.

Perhaps surprisingly, the decrease in household welfare and total surplus can also obtain when firms are perfectly competitive as illustrated in Figure 3(b). These findings suggests that a more lenient repossession policy may be preferable. For example, the firm could reposess the good only after a certain number of missed payments or only with some probability less than one. Indeed, a key innovation of the PAYGO model is that the punishment for missing a payment is not too severe. Failure to make a payment results in a punishment that is proportional to the flow value of consuming the good rather than the stock value, which is what happens with physical repossession.

4 Experiment: Background and Design

4.1 Fenix overview

As of mid-2019, Fenix had over 500,000 solar home system (SHS) customers across 6 countries in Sub-Saharan Africa.[10] They are the largest SHS provider in Uganda, accounting for a good share of the nearly 200,000 SHS units sold there.[11] Fenix's smallest, and most popular,

[10]See https://www.fenixintl.com/blog/ (Date accessed: October 29, 2020).

[11]See Table 8 of https://www.gogla.org/sites/default/files/resource_docs/global_off-grid_solar_market_report_h2_2018_opt.pdf

system is 10 Watts and is able to power LED lamps, a radio, and charge cell phones. Its biggest system is 34 Watts and can support a variety a small electrical appliances including, a fan, speakers, and a custom built 18.5-inch television.[12] Fenix's solar home systems differ in several ways from the solar panels on homes in the US and Western Europe. For one, they are roughly two orders of magnitude smaller than the typical solar panel installation on a US or Western European home and they are standalone, meaning they are not interconnected with the nationwide grid.

Like most SHS providers, Fenix offers its units through a PAYGO model.[13] Customers make a small down payment, less than $10, and can bring home a Fenix SHS. They then make daily payments using mobile money until they have paid for the system. If a customer does not make a payment, the SHS will temporarily lock, preventing the customer from using it until they make their next payment.

Fenix also uses the remote payment and locking technology to offer additional loans, such as their "school-fee loan." These are cash loans offered to the better-paying customers three times a year at the beginning of school terms. As with the original SHS loan, customers make a small down payment and then Fenix transfers money to the customer's mobile money account.[14] The deposit covers administrative fees and gives the customer a seven day grace period before the device is subject to being locked. After the grace period, if the customer does not make a daily payment, the system will lock and the customer will not be able to use it until the make their next payment.

Our study focused on a 300,000 Ugandan Shilling (UGX) loan (just over $80). The required down payment is 20% (60,000 UGX) and then daily payments are 3,000 UGX for 100 days. Fenix considers the loan to be paid off provided the customer makes nominal payments totaling 300,000 UGX within 145 days of the loan issue date. This arrangement implies that customers who take longer to repay face a lower effective interest rate. For instance, a customer who makes a payment every day pays an annual percentage rate of 168%, whereas a customer who makes a payment only two out of every three days pays

[12]Information about Fenix's system can be found https://www.fenixintl.com/product/ (Date accessed: October 29, 2020).

[13]Over 85% of solar home systems are sold on PAYGO.

[14]In separate experiment, we analyzed the impact of the down payment for the cash loan and found that it served as an important screening mechanism.

an annual percentage rate of only 112% (though is locked out 1/3 of the time while in repayment).

Customers who do not pay off the loan within 45 days of the target repayment date face interest charges of 2% per month on any remaining principal. In addition, failure to repay the loan in a timely manner renders customers ineligible for futures loan offers. After 180 days of no payments, the loan is considered to be in default and Fenix reserves the right to repossess the SHS system. Though customers are told that their SHS may be repossesed in default, in practice, only a very small fraction of defaults (less than 5%) result in physical repossession.

4.2 Fenix's customer base

Table 1, columns (1) and (2) compare our sample of Fenix customers to population-wide statistics from rural Uganda based on the World Bank Living Standards Measurement Study (LSMS). Fenix customers are more likely to be male and married and have more children than the typical rural Ugandan household. They also are more likely to be employed outside the agricultural sector and more likely to come from the (relatively more wealthy) central region.

4.3 Primary and secondary schooling in Uganda

Formal schooling in Uganda starts at roughly age 5. Primary school extends for seven years, through age 12. Secondary school is for children aged 13-20. Primary and secondary-aged children in Uganda have access to both government and privately run schools. In 2016, the most recent year for which data are available, 80% of primary-aged students attended government-run schools and 20% attended privately run schools. At the secondary level, over 50% of children attend private schools.[15] The government has offered a universal primary education program since 1997, although in practice not all students have access to subsidizied primary education, and even those that do incur expenses for uniforms, books, school lunches and other supplies.

[15]Statistics from the Uganda Ministry of Education and Sports at http://www.education.go.ug/wp-content/uploads/2019/07/FACT-SHEET-2016.pdf

School fees are typically due 3 times per year, in February, May and September. Two of the three due dates are not around any significant harvest, and hence are periods of low income across rural Uganda. In one study, 53% of families reported having their children sent home because they are not able to pay school fees.[16] In the Living Standards Measurement Survey, for households with school-aged-children (aged 5-20), median household school expenditures is roughly a third of median households income.

4.4 Design

We decompose the repayment effect into improvements via reduction in moral hazard and adverse selection. Figure 4 lays out the experimental design. Our universe of eligible loan recipients consisted of Fenix customers that had repaid the initial loan on their solar home system, and we further excluded customers who had an outstanding school fee loan.[17] In May 2019 we sent an SMS message to the 27,081 eligible customers inviting them to reply if they were interested in a school fee loan and 3,300 customers (12%) responded. We next randomly allocated the interested customers into four groups - a control group, a choice group, a locked group and an unlocked group. We collected administrative data on all of the customers in all four groups and we also sent our field teams to administer a baseline survey to households in each group to collect data on demographics (including number of school-aged children), socioeconomic variables, educational outcomes (including school enrollment, day to-day attendance, grade repetition, and expenditures), household borrowing, lending, and saving behavior, and access to financial services. Separately, our call center reached out to the households in each treatment group using the phone numbers to which we had sent the SMS messages. In the two main treatment groups - locked and unlocked - the call center explained that the customers were eligible for either a loan - locked and unlocked respectively - and were asked if they were interested in proceeding. While interest in the loan was high among both treatment groups, a larger share of households said, "Yes" if they were offered

[16] http://finclusion.org/uploads/file/reports/InterMedia

[17] Before our study, Fenix offered school fee loans to customers who had fewer than 30% of the days locked on their solar home system loan. Also, Fenix first offered customers 100,000 UGX loans, and, if those were successfully repaid, they would offer them larger loans. To increase the sample size for this study, Fenix relaxed both of these requirements.

an unlocked loan (83%) than households offered a locked loan (75%).

After the household had said yes to the loan, the field team explained to the set of households randomly allocated to the surprise unlock group that they would in fact be unlocked even though they had signed up for a locked loan. This "surprise," following Karlan and Zinman (2009), allows us to separately identify a pure moral hazard effect by comparing households that had selected into a locked loan, but then were randomly allocated into a surprise group that was in fact unlocked, to households that remained locked. In some cases, however, the field team reached the household and revealed the surprise before they had made the deposit. Essentially, we observed a multi-stage decision process, in which households first verbally expressed interest in the loan (labeled said "Yes" to a loan in Figure 4), but then only about half of those customers made the deposit and completed the paperwork to secure the loan. Given that some of the households in the "Surprise Unlock" group knew the surprise before they made the second decision (to pay the deposit and complete the paperwork), we consider households that were truly surprised (i.e., paid the deposit prior interaction with the field team) as a robustness check below.

The bottom row of Figure 4 indicates the share of households in each group that took the loan as a share of households that we were able reach.[18] Consistent with our model, we see a clear indication that the locked loan is less attractive than the unlocked loan: 40-42% of households take the locked loan compared to 47% who take the unlocked loan. Table A.1 in the Appendix explores whether there are significant differences in the characteristics of the households that took up the loan in the locked and unlocked categories. Altogether, most baseline characteristics are statistically indistinguishable across the two groups, suggesting that the locking may be screening on household characteristics that are not captured by other household variables.

5 Results

We are interested in the impact of the locking technology on both firm-level and customer-level outcomes and separate our discussion into those two categories.

[18]The choice group is not a central part of the experiment and discussed briefly below.

5.1 Firm-level Outcomes

Fenix set the loan pricing described in Section 4.1 (20% deposit and 100-day loan term). Naturally, profitability will be a closely rated to customers' *repayment rate*, defined as a customers' cumulative payments towards the principal divided by the total loan principal.[19] Figure 5(a) plots the repayment rates over time for customers in the locked, surprise unlocked, and unlocked treatment groups. Figure 5(b) plots the differences between the 3 groups.

Consistent with our model's suggestion that lockout increases firm profits, we see that repayment rates in the locked group are consistently higher than repayment rates in either the surprise unlocked group or unlocked group. Overall lockout appears to lead to nearly 13 percentage points higher repayments at 100 days, improving repayment rates from just above 45% to almost 60%. The moral hazard effect is derived by comparing repayment rates in the locked group to repayment rates in the surprise unlocked group, on the assumption that the selection mechanisms were the same in these groups as they both thought they would have locked loans when they enrolled. This accounts for the bulk of the overall effect, between 8-10 pp higher repayment. The adverse selection effect is derived by comparing repayment rates in the surprise unlocked group to the unlocked group, on the assumption that both groups faced the same incentive to repay conditional on signing up for the loan since they were both unlocked. This accounts for roughly 3-5 pp higher repayment.

Table 2 presents results from regression specifications of the following form:

$$r_i = \alpha + \beta * Treatment\ group_i + \epsilon_i \tag{6}$$

Where r_i is the repayment rate for household i through the loan day (column 1), α is a constant and ϵ_i is an error term. Every cell in the last three columns reflects a different specification of equation (6). The column labeled "Lockout" captures the overall lockout effect. Specifications in this column include households in the locked group and unlocked group and $Treatment\ group_i$ is equal to one for households in the locked group. Specifications in the column labeled "Adverse Selection" include households in the surprise unlocked group and the unlocked group and $Treatment\ group_i$ is equal to one for households in the surprise

[19]Fenix credits commissions to customers who refer other customers to Fenix, and we include payments from these commissions, although they account for less than 0.05% of total payments towards principal.

unlocked group. Specifications in the columns labeled "Moral Hazard" include households in the locked group and the surprise unlocked group and $Treatment\ group_i$ is equal to one for households in the locked group.

The results reflect the same differences as Figure 5 and the standard errors indicate that the overall lockout effect is significant at the 1% level, the moral hazard effect significant at the 5% level while the adverse selection effect is not statistically significant.

As an alternative measure of repayment, we consider the fraction of loans that have completed payments in Table 3. A loan is recorded as completed when the repayment rate equals one.Our results suggest that lockout leads to a 15 percentage point increase in the share of completed loans after 150 days, with moral hazard accounting for slightly more than two thirds third of the effect.

The results in Tables 2 and 3 reflect Local Average Treatment Effects (LATE) estimates, accounting for imperfect compliance (i.e., the fact that some customers who were supposed to be locked were unlocked for some days and vice versa). Altogether, fewer than 10% of the loan days were not in compliance. There were two general types of imperfect compliance: (1) administrative errors at the beginning of the experiment, and (2) customers who had additional transactions with Fenix over the study period, for example to upgrade their solar home system, and were sometimes switched to the wrong locking arrangement. See Appendix A Tables A.3, A.4, and A.5 for more details and for the Intent to Treat (ITT) estimates of the specifications reported in Tables 2 and 3, respectively.

5.1.1 Heterogeneity across customers

The key measure of Fenix's profitability is the internal rate of return (IRR) on the loans. Table 4 summarizes IRRs for customers in all three treatment groups and shows that lockout increased Fenix's profitability by approximately 5 pp month (60 pp annualized). As we explained in Section 4, Fenix expanded eligibility for their school fee loans to generate the sample for this study, which meant that households who had a larger number of days when their SHS was locked were included even though Fenix would not have offered cash loans to them under their usual business practices. To account for that, Table 4 reports the IRRs by

tercile of the number of days the household's SHS was locked.[20] Focusing on the first tercile, where the range of days locked is 0 to 6%, we see that locked loans lead to a nearly 5 pp per month higher IRR than unlocked loans, but the returns on the loans are all negative, even for the locked loans. For the second and third terciles, the difference between locked and unlocked is similar and even larger for the third tercile, and the returns are lower.

For perspective on the extent to which the negative IRRs are a function of the expanded loan eligibility criteria, we calculated IRRs for school fee loans that Fenix had offered in prior school terms (in 2018), broken into terciles in days locked for that portfolio of loans. Based on the range of days locked, reported in brackets, the prior school fee loans in the first two terciles are comparable to the loans in the first tercile of the study sample (if anything worse), yet the IRRs on the prior loans are considerably higher (and positive). This could be explained by the fact that the study offered 300,000 UGX loans to customers who had never had a cash loan, while the prior loans were smaller (100,000 UGX) for first-time borrowers.

Table 5 analyzes the treatment impact on repayment rates and loan completion for households that were above and below median number of days locked. This allows us to assess the extent to which customers with higher a priori risk levels had lower repayment and loan completion rates because of selection or moral hazard. The coefficients on the interaction term in Table 5 suggest that the lockout feature increased repayments and completion slightly more for riskier households (with above median number of days locked on their original solar home system loan). Interestingly, almost all of the impact for the higher risk households comes through the moral hazard effect and not through selection.

We also explored heterogeneity as a function of how quickly households accepted the loan. In particular, as noted above, some of the households in the surprise unlocked group were notified by our field staff that they would be unlocked before they made their deposits. It is possible that among these households, there were some differences in the households that followed through with the deposits for the loans compared to the locked group, meaning that the moral hazard effect in Figure 5 and Table 2 are overstated and the adverse selection

[20]Loans in each tercile are formed into a portfolio. The internal rate of return (IRR) is the discount rate that makes the net present value of cash flows on the portfolio equal to zero. Figure A.1 in the Appendix depicts repayment rates as a continuous function of days locked and suggests that the tercile cutoffs are sensible.

effect understated. (Note that this understatement does not impact the estimate of the overall lockout effect.) To explore by how much this is driving our decomposition results, we re-estimated versions of the specifications in Table 2 using only those households that committed to loan before they were visiting by our field staff. These results are reported in Table A.6 in the Appendix. Interestingly, the overall lockout effect is almost two times as large among this set of people – pointing to considerable heterogeneity which we explore in more detail below. The moral hazard effect is slightly smaller, but the overall conclusion that moral hazard explains the bulk of the effect remains.

Finally, we consider heterogeneity by the value households place on the services provided by the solar home system, the collateralized asset. Our model suggests that higher λ (stronger lockout) leads fewer households to accept the loan contract, conditional on their value for the good. Figure 7 analyzes loan take-up by respondent's stated willingness to pay for an extra day of access to their SHS.[21] We group the responses into three categories and show that customers with the highest willingness to pay are significantly less likely to accept a locked loan compared to an unlocked loan, while customers in the lower two groups are equally likely to accept them. We also see stronger effects of lockout for households with above median willingness to pay for solar (see Table A.15). For instance, the effect of lockout is 7 pp higher at 150 days for households with above (vs below) median willingness to pay. Although this difference is not statistically significant, it is both economically meaningful and consistent with the predictions of our model.

5.2 Household-level Outcomes

While the results presented thus far clearly suggest that lockout can improve firm profits, we are also interested in the impacts of the loans on household-level outcomes. At a high level, access to credit may facilitate welfare-enhancing investments for households. On the other hand, cash loans with high interest rates, especially if they are misunderstood by customers, may cause households to forego expenditures on other essential items, lowering

[21] Until recently, Fenix's systems did not record the number of hours of use by customer, so we could not use that as a revealed preference measure of value, although even average hours of usage would be an imperfect measure.

their overall welfare. Because the cash loans were offered at the beginning of the school term and marketed as "school-fee loans," we first examine schooling outcomes, and then present results on households' balance sheet.

5.2.1 Schooling outcomes

As discussed in Section 4, the loans we study were offered in May 2019, just before school fees were due for Term 2. The product was marketed as a school fee loan, though Fenix offered them to all eligible customers, regardless of whether they had school-aged children. In practice, almost 90% of our sample households had school-aged children and 91% who accepted a school-fee loan reported using it for education-related expenditures.

To understand whether the loans had an impact on schooling outcomes, we estimated version of the following equations:

$$\begin{aligned} y_i &= \alpha + \beta * \textit{Loan Offer}_i + \epsilon_i \\ y_i &= \alpha + \beta * \textit{Loan}_i + \epsilon_i \end{aligned} \tag{7}$$

where y_i is an outcome variable for household i. The first equation yields the intent to treat (ITT) estimates, where $\textit{Loan Offer}_i$ is an indicator for a household that was offered a loan through one of the three (locked, surprise unlocked, unlocked) groups. The second equation, estimated with *Loan Offer* as an instrument for $\textit{Loan}_i$ yields the local average treatment effect (LATE) for households that accepted loans. [22]

Table 6 reports results from estimates of (7) for several schooling-related outcomes. The first two columns report impacts on the share of 5 to 20-year-old children within a household who are enrolled in school and is estimated for households that had at least one child in that age range at baseline. The ITT results in Table A.8 suggest that the loan offer increases the share enrolled by almost 3 percentage points, and the LATE results in Table 6 indicate that 6 percent more of the households that took loans had all of their children enrolled at school. Given that 88 percent of children in the control group are enrolled, this suggests that access

[22] We also estimated specifications that allowed the loan impacts to vary by treatment group but saw no significant differences between the groups.

to the school-fee loan reduces the share of children who are not enrolled by half.[23]

The third and fourth columns on Table 6 analyze the impact on monthly absences from school for households that had at least one child enrolled. The coefficient estimates suggest no meaningful impact on days absent, and we can rule out a reduction of more than 0.7 days given the standard errors. In the fifth and sixth columns, we see that expenditures for school-related items (including school fees, uniforms, supplies, transport and meals) increased by over 40% for households that received loans. This increase is too large to reflect the results from the first two columns - that 6% of the households started paying for school fees - and suggests that the loans allowed households whose children were already fully enrolled to increase expenditures.

Table 7 presents results on enrollment and expenditures by child, separating outcomes for males and females. This table suggests that the increased enrollment was concentrated among male children, while the increased expenditure was concentrated among female children.

In summary, Fenix's loans had a large impact on educational outcomes. These findings suggest that households did not have another source of liquidity to use for schooling-related expenditures. The Living Standards Measurement Survey (LSMS) reinforces this interpretation: only 3% of households in the LSMS had a loan with a commercial bank, only 2% had a loan with a credit institution and only 1% had a loan with a microfinance institution.

5.2.2 Overall household financial position

While the results on schooling suggest that the school fee loans had beneficial impacts on households, we are also interested in understanding effects on households' overall financial positions.

Table 8 reports results on household asset purchases and sales, as well as borrowing. The results are noisy and statistically insignificant, although we can rule out large negative impacts on households that took loans, such as a significant increase in asset sales or reduction in purchases. For additional perspectives on household's financial position, we asked a series

[23]Enrollment rates among households in our sample appear roughly comparable to enrollment rates for the population. According to the Living Standards Measurement Survey, nationwide 91% of primary school-aged children and 68% of secondary school-aged children are enrolled at school.

of questions about shocks households had experienced, including financial shocks, and their ability to weather those shocks. The results are summarized in the Appendix. Again, we see no systematic or significant difference between households that were offered loans and the control group.

6 Conclusion

In this paper, we explore a novel form of financial contracting facilitated by lockout technology. Rather than permanently repossess collateral, the lender temporarily disables the flow value of the collateral to the borrower when the borrower misses a payment. We show that loans collateralized with lockout exhibit significantly higher repayment. About 1/3 of the increase in repayment can be attributed to (ex-ante) selection and about 2/3 to (ex-post) moral hazard. Access to these loans had positive effects on educational outcomes and did not have negative effects on household's overall balance sheet. There are numerous other potential applications in which this innovation could be utilized to provide cheaper access to credit, which are especially promising in economies with an underdeveloped banking and financial system.

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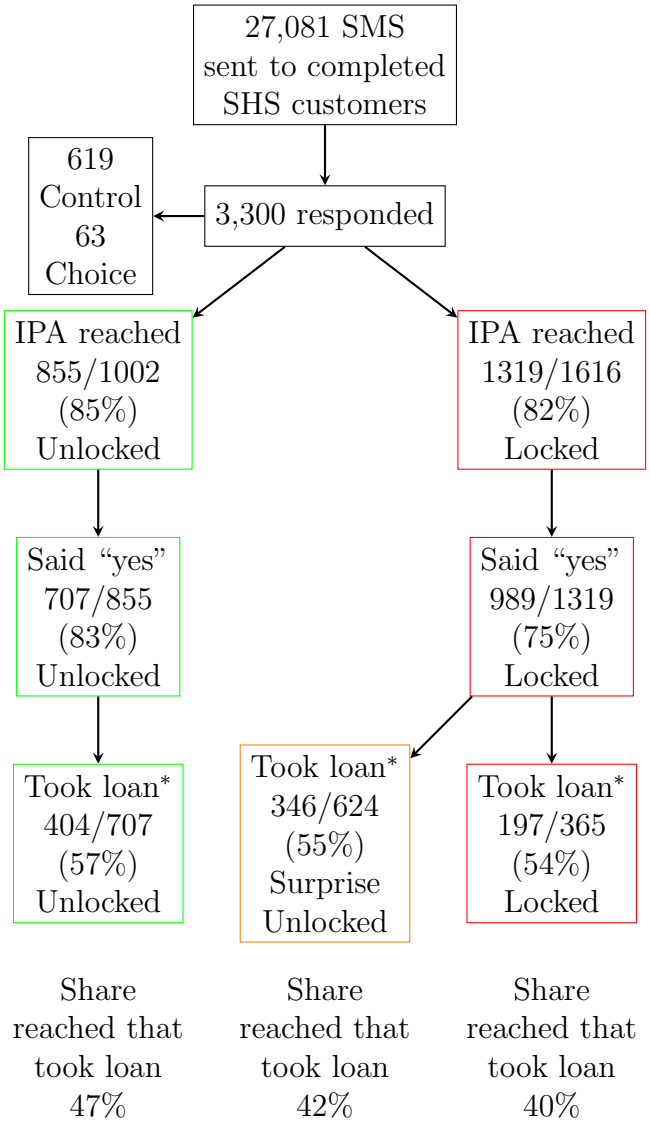
7 Figures and Tables

Figure 4: Consort Statement



Note: * refers to signing the necessary paperwork for a loan and paying the required deposit.

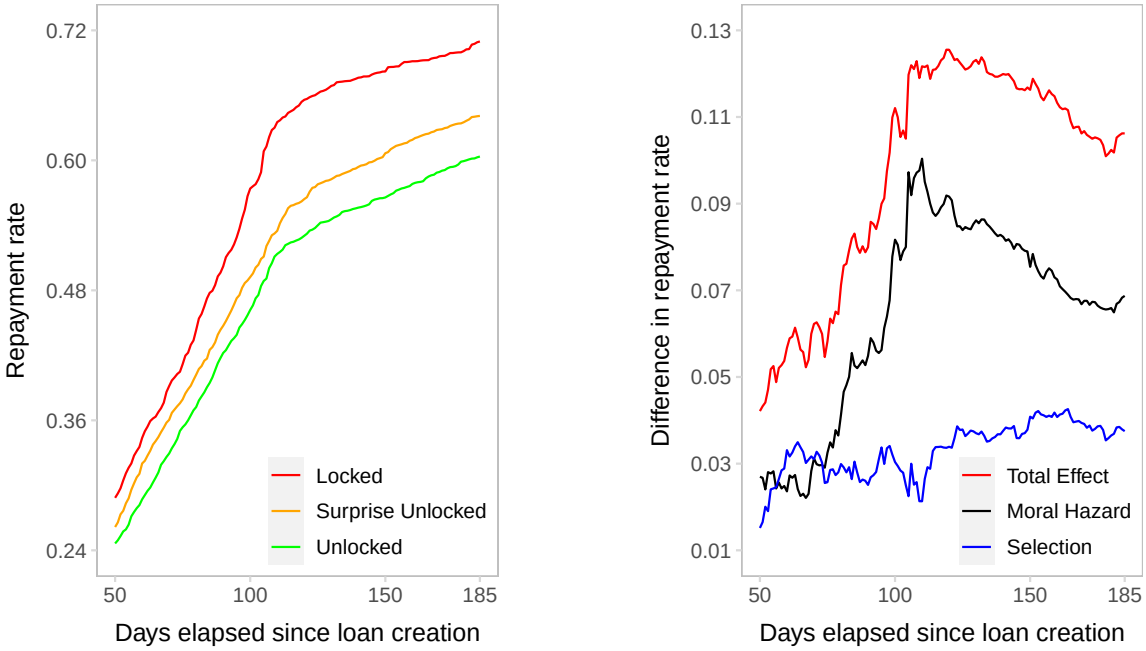
Table 1: Descriptive Statistics of Enrollee Characteristics from Administrative Data

Characteristic	(1) Uganda LSMS	(2) SMS sent to	(3) Said yes to loan	(4) Took up loan
Risk				
Proportion of days locked at SMS	-	0.13	0.16***	0.16
		(0.15)	(0.15)	(0.16)
Demographics				
Age (years)	47	46***	45***	45
	(21)	(12)	(11)	(11)
Female (proportion)	0.33	0.23***	0.14***	0.13
	(0.59)	(0.42)	(0.35)	(0.34)
Married (proportion)	0.69	0.90***	0.92***	0.93
	(0.60)	(0.30)	(0.27)	(0.25)
Number of children	3.0	4.3***	4.1***	3.9
	(3.1)	(2.9)	(2.8)	(2.5)
Occupation (proportion)				
Agriculture or Non-employed	0.64	0.37***	0.25***	0.23
	(0.59)	(0.48)	(0.43)	(0.42)
Non-professional	0.23	0.39***	0.37*	0.38
	(0.51)	(0.49)	(0.48)	(0.48)
Other	0.05	0.08***	0.09**	0.08
	(0.28)	(0.27)	(0.29)	(0.28)
Professional	0.08	0.17***	0.29***	0.31
	(0.33)	(0.38)	(0.46)	(0.46)
Region (proportion)				
Central	0.39	0.44***	0.35***	0.36
	(0.60)	(0.50)	(0.48)	(0.48)
Eastern	0.29	0.28	0.37***	0.36
	(0.52)	(0.45)	(0.48)	(0.48)
Western	0.32	0.28***	0.28	0.29
	(0.59)	(0.45)	(0.45)	(0.45)
n	2341	27081	1696	947

Note: Standard deviations in parentheses. The World Bank Living Standards Measurement Study (LSMS) - Uganda National Panel Survey information featured in (1) comes from the 2015/2016 wave. Columns (2) through (4) comes from Fenix administrative data. Sample statistics for the UNPS sample are weighted

using probability weights. For Demographics, the UNPS sample statistics relate to the head of household, while the Fenix customer statistics relate to the customer who signed with Fenix. For Occupation using the Fenix data, "Agriculture or Non-employed" includes Cattle Trader, Farmer, Fisherman, and Not Employed; "Professional" includes Accountant, Banker, Broker, Electrician, Engineer, Government / Civil Servant, Health Worker, Journalist, Mechanic / Technician, NGO Worker, Office Work, Police, Security Guard, Teacher, Tour Guide, UPDF, and Uganda Prisons; "Non-professional" includes Boda Boda, Butcher, Carpenter, Construction, Driver, Herbalist, MM Agent, Market Trader, Money Changer, Religious Leader, Shop Keeper, Small Business Owner, Tailor, and Taxi Operator. Occupation for the UNPS sample followed a similar categorization. (3) is a subset of (2) and (4) is a subset of (3). The results from tests of differences that compare (1) to (2), (2) to (3), and (3) to (4) are displayed in (2), (3), and (4), respectively. Customers who were assigned to a Menu of Choice treatment are dropped from (2), (3), and (4) and only comprised 2% of those samples. Although the sampling strategy was to drop individuals living in the Northern region, (2) includes 29 individuals who were registered as having lived in the Northern region and who were targeted for the SMS messages. * $p < .10$, ** $p < .05$, *** $p < .01$

Figure 5: Loan repayment rates and differences in repayment rates

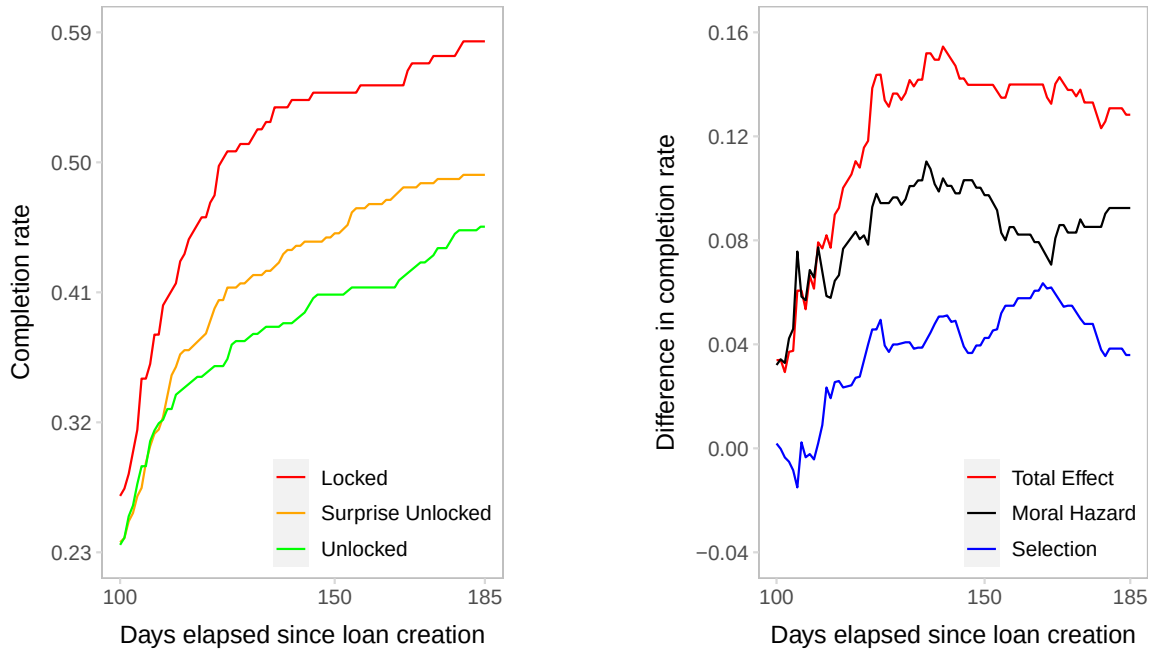


(a) Loan repayment rates

(b) Differences in repayment rates

Note: Average loan repayment rates over days elapsed since loan creation, by treatment, are in Panel A, and difference in average loan repayment rates over days elapsed since loan creation, by effect, are in Panel B. In Panel B, "Total Effect" displays the difference in average repayment rates between the Locked and Unlocked groups, "Moral Hazard" displays the difference in average repayment rates between the Locked and Surprise Unlocked groups, and "Selection" displays the difference in average repayment rates between the Surprise Unlocked and Unlocked groups. (Difference in) average repayment rates are displayed over the sample of 947 loans, of which 197 are Locked loans, 346 are Surprise Unlocked loans, and 404 are Unlocked loans.

Figure 6: Loan completion rates and differences in completion rates



(a) Loan completion rates

(b) Differences in completion rates

Note: Average loan completion rates over days elapsed since loan creation, by treatment, are in Panel A, and difference in average loan completion rates over days elapsed since loan creation, by effect, are in Panel B. In Panel B, "Total Effect" displays the difference in average completion rates between the Locked and Unlocked groups, "Moral Hazard" displays the difference in average completion rates between the Locked and Surprise Unlocked groups, and "Selection" displays the difference in average completion rates between the Surprise Unlocked and Unlocked groups. (Difference in) average completion rates are displayed over the sample of 947 loans, of which 197 are Locked loans, 346 are Surprise Unlocked loans, and 404 are Unlocked loans.

Table 2: Tests of Lockout, Adverse Selection and Moral Hazard on Loan Repayment (LATE)

Loan day	Mean Unlocked	Lockout	Adverse Selection	Moral Hazard
100	0.46	0.13***	0.03	0.10**
		(0.04)	(0.03)	(0.04)
150	0.57	0.13***	0.05	0.09**
		(0.04)	(0.03)	(0.04)
185	0.60	0.12***	0.04	0.08*
		(0.04)	(0.03)	(0.04)
n		601	750	543

Note: Standard errors in parentheses. Loan repayment is measured by the cumulative proportion of the loan principal repaid. The above results display the Local Average Treatment Effect (LATE), which measures the average treatment effect on loan repayment for compliers, using the share of days in compliance as the endogenous variable (see the Appendix for Intent to Treat (ITT) results). The analysis is run on samples at either the 100th, 150th, or 185th day from origination for the Completed customer sample. "Lockout" captures the difference in the repayment rate between the Unlocked and Locked samples, "Adverse Selection" captures the difference in the repayment rate between the Unlocked and Surprise Unlocked samples, and "Moral Hazard" captures the difference in the repayment rate between the Surprise Unlocked and Locked samples. * $p < .10$, ** $p < .05$, *** $p < .01$

Table 3: Tests of Lockout, Adverse Selection and Moral Hazard on Loan Completion (LATE)

Loan day	Mean Unlocked	Lockout	Adverse Selection	Moral Hazard
110	0.32	0.09*	0.002	0.09*
		(0.05)	(0.04)	(0.05)
150	0.41	0.16***	0.05	0.11**
		(0.05)	(0.04)	(0.05)
185	0.46	0.15***	0.04	0.11**
		(0.05)	(0.04)	(0.05)
n		601	750	543

Note: Standard errors in parentheses. Loan completion describes whether the loan principal has been repaid. The above results display the Local Average Treatment Effect (LATE), which measures the average treatment effect on loan completion for compliers, using the share of days in compliance as the endogenous variable (see the Appendix for Intent to Treat (ITT) results). The analysis is run on samples at either the 110th, 150th, or 185th day from origination for the Completed customer sample. "Lockout" captures the difference in the completion rate between the Unlocked and Locked samples, "Adverse Selection" captures the difference in the completion rate between the Unlocked and Surprise Unlocked samples, and "Moral Hazard" captures the difference in the completion rate between the Surprise Unlocked and Locked samples. * $p < .10$, ** $p < .05$, *** $p < .01$

Table 4: Monthly IRRs of Loan Portfolios

Treatment Group	Account percent locked			All	n
	1st tercile	2nd tercile	3rd tercile		
Locked	-0.6%	-3.7%	-8.2%	-4.3%	197
	[0.00, 0.06]	[0.06, 0.19]	[0.20, 0.57]	[0.00, 0.57]	
Unlocked	-5.3	-7.0	-14.7	-9.0	404
	[0.00, 0.06]	[0.06, 0.20]	[0.20, 0.64]	[0.00, 0.64]	
Prior School Fee Loans (Locked)	6.7	6.3	3.0	5.1	1377
	[0.00, 0.04]	[0.04, 0.13]	[0.13, 0.30]	[0.00, 0.30]	

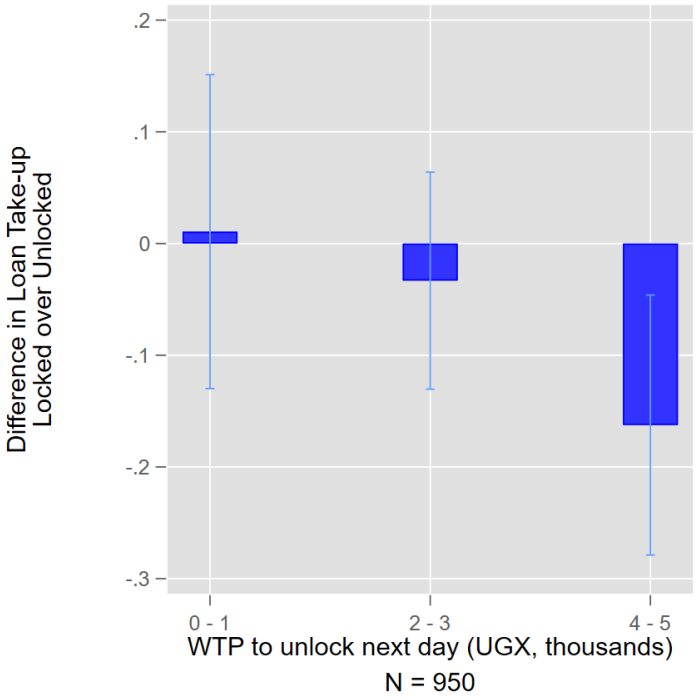
Note: Loans in each treatment group are sorted by proportion of days locked at SMS and divided into equal-sized terciles. Loans in each tercile are formed into a portfolio. The internal rate of return (IRR) is the discount rate that makes the net present value of cash flows on the portfolio equal to zero. The IRRs of portfolios formed using all loans in each treatment group are also reported. The range of the fraction of days locked is reported in square brackets.

Table 5: Tests of Lockout, Adverse Selection, and Moral Hazard, Risk (Interactions Model) (LATE)

	Lockout	Adverse Selection	Moral Hazard
On Loan Repayment at 150 days			
Treatment	0.11*	0.10**	0.01
	(0.06)	(0.05)	(0.06)
Treatment × Median risk or above	0.04	-0.10	0.15*
	(0.08)	(0.07)	(0.08)
Median risk or above	-0.16***	-0.15***	-0.26***
	(0.04)	(0.04)	(0.05)
Constant	0.64***	0.64***	0.73***
	(0.03)	(0.03)	(0.03)
On Loan Completion at 185 days			
Treatment	0.13*	0.08	0.05
	(0.07)	(0.06)	(0.07)
Treatment × Median risk or above	0.03	-0.08	0.13
	(0.10)	(0.08)	(0.10)
Median risk or above	-0.18***	-0.18***	-0.27***
	(0.05)	(0.05)	(0.06)
Constant	0.54***	0.55***	0.62***
	(0.04)	(0.04)	(0.04)
n	601	750	543

Note: Standard errors in parentheses. Loan repayment is measured by the cumulative proportion of the loan principal repaid. Loan completion describes whether the loan principal has been repaid. The above results display the Local Average Treatment Effect (LATE), which measures the average treatment effect on either loan repayment or loan completion for compliers, using the share of days in compliance as the endogenous variable (see the Appendix for Intent to Treat (ITT) results). The analysis is run on the sample at the 150th day (for loan repayment) or 185th day (for loan completion) from origination for the Completed customer sample. Under "Lockout" where the subsample is those who were assigned Locked or Unlocked, "Treatment" captures the treatment effect of Locked. Under "Adverse Selection" where the subsample is those who were assigned Unlocked or Surprise Unlocked, "Treatment" captures the treatment effect of Surprise Unlocked. Under "Moral Hazard" where the subsample is those who were in assigned Surprise Unlocked and Locked, "Treatment" captures the treatment effect of Locked. "Median risk or above" is an indicator for whether the customer had their solar home system locked for 11 percent or more of its history by early May 2019, right before the start of the experiment. "×" represents an interaction. * $p < .10$, ** $p < .05$, *** $p < .01$

Figure 7: Effect of Lockout on Loan Take-up by Willingness to Pay



Note: This figure covers the sample of 952 individuals, of which 344 are treated with Locked loans and 608 are treated with Unlocked loans. Individuals treated with Surprise unlocked loans are excluded from this figure. Individuals with willingness to pay to unlock next day being 0 or 1,000 UGX are in the first group, being 2,000 or 3,000 UGX in the second group, and being 4,000 or 5,000 in the third group. The differences in take-up between individuals treated with Locked and Unlocked loans are plotted and 95% confidence intervals are along with the bars.

Table 6: Education Outcomes, Household-level (LATE)

	Enrollment	Days absent	Log school expenditures
Loan	0.0614**	0.0294	0.355**
	(0.0303)	(0.342)	(0.169)
Constant	0.875***	1.277***	12.22***
	(0.0147)	(0.167)	(0.0825)
n	1698	1636	1636

Note: Standard errors in parentheses. Results relate to Term 2 outcomes. The above results display the Local Average Treatment Effect (LATE), which measures the average treatment effect for compliers, using actual receipt of a school fee loan as the endogenous variable (see the Appendix for Intent to Treat (ITT) results). "Enrollment" describes the share of school-aged children (individuals aged 5-20) enrolled in Term 2 within the household, and is conditional on having at least one school-aged child within the household at endline. "Days absent" describes the average days of school missed per month, per enrolled school-aged child, and is conditional on having at least one school-aged child enrolled at endline in Term 2. "School expenditures" describes the average school expenditure per enrolled school-aged child and is conditional on having at least one school-aged child enrolled at endline in Term 2. School expenditures include expenditures on school fees, supplies (uniforms, pens, pencils, notebooks, etc), transport, and school meals. School expenditures are winsorized at the 99th percentile. * $p < .10$, ** $p < .05$, *** $p < .01$

Table 7: Education Outcomes for School Aged Children (LATE)

	Enrollment		Log school expenditures	
	Male	Female	Male	Female
Loan	0.0726*	-0.0258	0.254	0.599**
	(0.0373)	(0.0358)	(0.205)	(0.285)
P value from Chow test		0.03		0.26
Outcome mean	0.912	0.900	12.09	12.15
n	2762	2908	2508	2606

Note: Standard errors in parentheses. Standard errors are clustered at the household level. Results relate to Term 2 outcomes. The above results display the Local Average Treatment Effect (LATE), which measures the average treatment effect for compliers, using actual receipt of a school fee loan as the endogenous variable (see the Appendix for Intent to Treat (ITT) results). School expenditures are conditional on enrollment at endline in Term 2. School expenditures include expenditures on school fees, supplies (uniforms, pens, pencils, notebooks, etc), transport, and school meals. School expenditures are winsorized at the 99th percentile. The p value from the Chow test compares the treatment effect for males to that of females. * $p < .10$, ** $p < .05$, *** $p < .01$

Table 8: Household Balance Sheet Effects, calculated (semi-)elasticities (LATE)

	Asset purchases (IHST)	Asset sales (IHST)	Money borrowed (IHST)	Net difference (IHST)
Loan	1.010	-0.451	0.037	-0.570
	(1.471)	(0.486)	(0.899)	(0.788)

Note: Standard errors in parentheses. Asset purchases, asset sales, and money borrowed are winsorized at the 99th percentile. The above analysis uses the Local Average Treatment Effect (LATE) to derive semi-elasticities. The LATE measures the average treatment effect for compliers, using actual receipt of a school fee loan type (or any school fee loan) as the endogenous variable (see the Appendix for Intent to Treat (ITT) results). "Net difference" records the difference between asset purchases and asset sales, minus money borrowed. Winsorizing takes place before IHST transformation. For 31 individuals who reported a source of a loan as ReadyPay, the amount of the school fee loan was added back into the total amount reported to have been borrowed. Loan refers to the semi-elasticity calculated following the exact method from Bellemare and Wichman (2019), following arguments from Halvorsen and Palmquist (1980), Kennedy (1981) and Giles (1982). * $p < .10$, ** $p < .05$, *** $p < .01$

A Appendix

Table A.1: Characteristics of those who take-up loans (dropping Surprise Unlocked)

	Unlocked	Locked	N
Percent of days locked at SMS	16.2	14.5	468
	(15.6)	(14.1)	
Household head characteristics			
Age	42.9	44.2	468
	(10.0)	(11.3)	
Female	0.11	0.10	468
	(0.31)	(0.31)	
Household head occupation			
Family business or farm	0.50	0.65***	468
	(0.50)	(0.48)	
Self-employed	0.60	0.64	468
	(0.49)	(0.48)	
Outside the home	0.36	0.33	468
	(0.48)	(0.47)	
Number of school aged children	3.1	3.2	468
	(2.1)	(2.1)	
Total yearly household income per adult equivalent (UGX, millions)	1.3	1.1	468
	(1.2)	(0.9)	
Value of assets per adult equivalent (UGX, millions)	1.1	1.2	468
	(1.4)	(1.5)	
Share of 5k UGX kept in risk game	0.36	0.37	468
	(0.25)	(0.25)	
WTP to unlock next day (UGX, thousands)	3.0	2.9	468
	(1.5)	(1.5)	
Hours to nearest ReadyPay Service Center	0.9	1.0	468
	(0.8)	(0.8)	

Standard deviations in parentheses. Values in UGX are winsorized at the 99th percentile. Tests of differences in means are carried out between Unlocked and Locked. * $p < .10$, ** $p < .05$, *** $p < .01$

Table A.2: Baseline Characteristics

Characteristic	Locked	Surprise Unlocked	Unlocked	Control	n
Risk					
Percent of days locked at SMS (%)	14.7 (15.3)	15.2 (15.5)	16.1 (15.2)	14.0 (14.5)	2133
Household head					
Age (years)	43.0 (11.0)	43.8 (11.1)	43.3 (10.6)	43.5 (11.1)	2122
Female (proportion)	0.13 (0.34)	0.12 (0.32)	0.11 (0.32)	0.11 (0.31)	2125
Married (proportion)	0.89 (0.32)	0.88 (0.32)	0.85 (0.35)	0.86 (0.34)	2125
Household head occupation (proportion)					
Family business or farm	0.59 (0.49)	0.56 (0.50)	0.53 (0.50)	0.56 (0.50)	2125
Self-employed	0.60 (0.49)	0.63 (0.48)	0.60 (0.49)	0.59 (0.49)	2123
Outside the home	0.35 (0.48)	0.36 (0.48)	0.37 (0.48)	0.34 (0.47)	2125
Demographics					
Number of people in household	6.6 (2.7)	6.6 (3.0)	6.6 (2.7)	6.6 (2.7)	2125
Number of children aged 5-20 enrolled in school	2.7 (1.9)	2.7 (2.0)	2.7 (1.9)	2.7 (2.0)	2125
Financial information					
Amount spent on lighting, year (UGX, millions)	0.1 (0.3)	0.1 (0.3)	0.2 (0.4)	0.2 (0.4)	2121
Total household income, year (UGX, millions)	5.2 (4.7)	5.5 (5.0)	5.3 (5.0)	5.8 (5.5)	2094
Value of assets (UGX, millions)	5.3 (7.2)	4.8 (6.0)	5.1 (7.0)	5.3 (7.0)	2125
Borrowing					
Borrowed in last 12 months (proportion)	0.60 (0.49)	0.60 (0.49)	0.62 (0.49)	0.63 (0.48)	2120

Money borrowed in last 12 months (UGX, millions)	1.2 (2.7)	1.1 (2.5)	1.3 (2.7)	1.2 (2.5)	2117
Ever refused for loan in last 12 months (proportion)	0.13 (0.34)	0.14 (0.35)	0.15 (0.35)	0.20 (0.40)	2119
Took a microfinance loan in last 12 months (proportion)	0.07 (0.26)	0.06 (0.25)	0.08 (0.28)	0.07 (0.26)	2120

Note: Standard deviations in parentheses. Values in UGX are winsorized at the 99th percentile.

Table A.3: Share of Days in Compliance, by Treatment

Loan day	Locked	Surprise Unlocked	Unlocked
50	0.92	0.91	0.93
	(0.27)	(0.23)	(0.21)
100	0.92	0.93	0.94
	(0.27)	(0.20)	(0.20)
150	0.92	0.94	0.95
	(0.27)	(0.20)	(0.20)
185	0.92	0.94	0.95
	(0.26)	(0.20)	(0.20)
n	197	346	404

Note: Standard deviations in parentheses. The analysis is run on samples of the share of days in compliance at either the 50th, 100th, 150th day, or 185th day from origination for the Completed customer sample.

Table A.4: Tests of Lockout, Adverse Selection and Moral Hazard on Loan Repayment (ITT)

Loan day	Mean Unlocked	Lockout	Adverse Selection	Moral Hazard
100	0.46	0.11***	0.03	0.08**
		(0.03)	(0.03)	(0.03)
150	0.57	0.12***	0.04	0.08**
		(0.04)	(0.03)	(0.04)
185	0.60	0.11***	0.04	0.07*
		(0.04)	(0.03)	(0.04)
n		601	750	543

Note: Standard errors in parentheses. Loan repayment is measured by the cumulative proportion of the loan principal repaid. The above results display the Intent to Treat (ITT) analysis, which measures the average effect of assignment on loan repayment. The analysis is run on samples at either the 100th, 150th, or 185th day from origination for the Completed customer sample. "Lockout" captures the difference in the repayment rate between the Unlocked and Locked samples, "Adverse Selection" captures the difference in the repayment rate between the Unlocked and Surprise Unlocked samples, and "Moral Hazard" captures the difference in the repayment rate between the Surprise Unlocked and Locked samples. * $p < .10$, ** $p < .05$, *** $p < .01$

Table A.5: Tests of Lockout, Adverse Selection and Moral Hazard on Loan Completion (ITT)

Loan day	Mean Unlocked	Lockout	Adverse Selection	Moral Hazard
110	0.32	0.08*	0.002	0.08*
		(0.04)	(0.03)	(0.04)
150	0.41	0.14***	0.04	0.10**
		(0.03)	(0.04)	(0.04)
185	0.46	0.13***	0.04	0.09**
		(0.04)	(0.04)	(0.04)
n		601	750	543

Note: Standard errors in parentheses. Loan completion describes whether the loan principal has been repaid. The above results display the Intent to Treat (ITT) analysis, which measures the average effect of assignment on loan completion. The analysis is run on samples at either the 110th, 150th, or 185th day from origination for the Completed customer sample. "Lockout" captures the difference in the completion rate between the Unlocked and Locked samples, "Adverse Selection" captures the difference in the completion rate between the Unlocked and Surprise Unlocked samples, and "Moral Hazard" captures the difference in the completion rate between the Surprise Unlocked and Locked samples. * $p < .10$, ** $p < .05$, *** $p < .01$

Table A.6: Tests of Lockout, Adverse Selection, and Moral Hazard on Loan Repayment, Early Adopters

Loan day	Mean Unlocked	Lockout		Adverse Selection		Moral Hazard	
		ITT	LATE	ITT	LATE	ITT	LATE
100	0.47	0.13**	0.17**	0.02	0.02	0.12**	0.15**
		(0.06)	(0.07)	(0.05)	(0.06)	(0.06)	(0.07)
150	0.55	0.18***	0.22***	0.08	0.09	0.10*	0.13*
		(0.06)	(0.07)	(0.05)	(0.06)	(0.06)	(0.07)
185	0.60	0.17***	0.21***	0.08	0.09	0.09	0.11
		(0.06)	(0.07)	(0.05)	(0.06)	(0.06)	(0.07)
n		220	220	269	269	193	193

Note: Standard errors in parentheses. The samples are further restricted to those individuals who had received the baseline survey after placing the loan deposit or who had not received a baseline survey (Early Adopters). Loan repayment is measured by the cumulative proportion of the loan principal repaid. The Intention to Treat (ITT) measures the average effect of assignment on loan repayment, while the Local Average Treatment Effect (LATE) measures the average treatment effect on loan repayment for compliers, using the share of days in compliance as the endogenous variable. The analysis is run on samples at either the 100th, 150th, or 185th day from origination for the Completed customer sample. "Lockout" captures the difference in the repayment rate between the Unlocked and Locked samples, "Adverse Selection" captures the difference in the repayment rate between the Unlocked and Surprise Unlocked samples, and "Moral Hazard" captures the difference in the repayment rate between the Surprise Unlocked and Locked samples. * $p < .10$, ** $p < .05$, *** $p < .01$

Table A.7: Tests of Lockout, Adverse Selection, and Moral Hazard on Loan Completion, Early Adopters

Loan day	Mean Unlocked	Lockout		Adverse Selection		Moral Hazard	
		ITT	LATE	ITT	LATE	ITT	LATE
110	0.34	0.10	0.12	-0.01	-0.02	0.11	0.14
		(0.07)	(0.09)	(0.06)	(0.07)	(0.07)	(0.09)
150	0.42	0.16**	0.20**	0.08	0.09	0.09	0.11
		(0.07)	(0.09)	(0.06)	(0.07)	(0.07)	(0.09)
185	0.47	0.20***	0.24***	0.07	0.09	0.13*	0.16*
		(0.07)	(0.09)	(0.06)	(0.07)	(0.07)	(0.09)
n		220	220	269	269	193	193

Note: Standard errors in parentheses. Loan completion describes whether the loan principal has been repaid. The samples are further restricted to those individuals who had received the baseline survey after placing the loan deposit or who had not received a baseline survey (Early Adopters). The Intention to Treat (ITT) measures the average effect of assignment on loan completion, while the Local Average Treatment Effect (LATE) measures the average treatment effect on loan completion for compliers, using the share of days in compliance as the endogenous variable. The analysis is run on samples at either the 110th, 150th, or 185th day from origination for the Completed customer sample. "Lockout" captures the difference in the completion rate between the Unlocked and Locked samples, "Adverse Selection" captures the difference in the completion rate between the Unlocked and Surprise Unlocked samples, and "Moral Hazard" captures the difference in the completion rate between the Surprise Unlocked and Locked samples. * $p < .10$, ** $p < .05$, *** $p < .01$

Table A.8: Education Outcomes, Household-level (ITT)

	Enrollment	Days absent	Log school expenditures
Loan	0.0277**	0.0133	0.161**
	(0.0137)	(0.155)	(0.0759)
Constant	0.880***	1.280***	12.25***
	(0.0124)	(0.140)	(0.0687)
n	1698	1636	1636

Note: Standard errors in parentheses. Results relate to Term 2 outcomes. The above results display the Intent to Treat (ITT) analysis, which measures the average effect of assignment to a loan. "Enrollment" describes the share of school-aged children (individuals aged 5-20) enrolled in Term 2 within the household, and is conditional on having at least one school-aged child within the household at endline. "Days absent" describes the average days of school missed per month, per enrolled school-aged child, and is conditional on having at least one school-aged child enrolled at endline in Term 2. "School expenditures" describes the average school expenditure per enrolled school-aged child and is conditional on having at least one school-aged child enrolled at endline in Term 2. School expenditures include expenditures on school fees, supplies (uniforms, pens, pencils, notebooks, etc), transport, and school meals. School expenditures are winsorized at the 99th percentile. * $p < .10$, ** $p < .05$, *** $p < .01$

Table A.9: Education Outcomes for School Aged Children (ITT)

	Enrollment		Log school expenditures	
	Male	Female	Male	Female
Loan	0.0338**	-0.0116	0.120	0.277**
	(0.0172)	(0.0161)	(0.0972)	(0.130)
P value from Chow test		0.03		0.28
Outcome mean	0.912	0.900	12.09	12.15
n	2762	2908	2508	2606

Note: Standard errors in parentheses. Standard errors are clustered at the household level. Results relate to Term 2 outcomes. School expenditures are conditional on enrollment at endline in Term 2. The above results display the Intent to Treat (ITT) analysis, which measures the average effect of assignment to a loan. School expenditures include expenditures on school fees, supplies (uniforms, pens, pencils, notebooks, etc), transport, and school meals. School expenditures are winsorized at the 99th percentile. The p value from the Chow test compares the treatment effect for males to that of females. * $p < .10$, ** $p < .05$, *** $p < .01$

Table A.10: Shocks over the past 6 months

	(1) Proportion shocks experienced	(2) Proportion shocks experienced	(3) How worried are you about this?	(4) How worried are you about this?
	Shock Category A: Problem With Money			
Assigned Locked loan	0.0171		0.0361	
	(0.0255)		(0.0233)	
Assigned Surprise Unlocked loan	-0.00327		0.0113	
	(0.0227)		(0.0209)	
Assigned Unlocked loan	0.0229		0.00704	
	(0.0225)		(0.0205)	
Assigned any loan		0.0117		0.0151
		(0.0199)		(0.0182)
Constant	0.414***	0.414***	0.729***	0.729***
	(0.0180)	(0.0180)	(0.0165)	(0.0165)
n	1895	1895	1409	1409
	Shock Category B: Money Matters For Coping			
Assigned Locked loan	-0.00433		0.00952	
	(0.0168)		(0.0185)	
Assigned Surprise Unlocked loan	-0.00707		-0.00613	
	(0.0150)		(0.0167)	
Assigned Unlocked loan	0.0139		0.0107	
	(0.0149)		(0.0165)	
Assigned any loan		0.00184		0.00416
		(0.0131)		(0.0146)
Constant	0.343***	0.343***	0.832***	0.832***
	(0.0119)	(0.0119)	(0.0131)	(0.0131)
n	1895	1895	1660	1660
	Shock Category C: Money Doesn't Help			
Assigned Locked loan	-0.00791		0.0652	
	(0.0120)		(0.0463)	
Assigned Surprise Unlocked loan	-0.0123		0.0577	
	(0.0107)		(0.0407)	
Assigned Unlocked loan	-0.0163		0.0317	
	(0.0106)		(0.0403)	

Assigned any loan		-0.0129		0.0490
		(0.00937)		(0.0350)
Constant	0.0896***	0.0896***	0.694***	0.694***
	(0.00847)	(0.00847)	(0.0311)	(0.0311)
n	1895	1895	458	458

Note: Standard errors in parentheses. Shock Category A gathers together the following experiences over the last 6 months: not having enough money for basic needs such as food and clothing; not having enough money for other living home expenses; being unable to educate all of your children; not having enough money for medicines and medical treatment; debts owed to others. Shock Category B gathers together the following experiences over the last 6 months: health problems or illness; an accident or disaster; difficulty finding work; death of a family member; job loss; weather affecting your crops. Shock Category C gathers together the following experiences over the last 6 months: problems at home with relatives; problems with people in other tribes; idleness of your children or spouse; alcohol consumption of your children or spouse. Columns (1) and (2) use the proportion of shocks within a category that one is said to have experienced over the last 6 months as the dependent variable. Columns (3) and (4) use the average value of the likert-scale values transformed to 0-1 scales, out of the shocks experienced within a category, as the dependent variable. The reference group is the Control group that was not assigned any school fee loan. * $p < .10$, ** $p < .05$, *** $p < .01$

Table A.11: Household Balance Sheet Effects (LATE)

	Asset purchases (IHST)	Asset purchases (IHST)	Asset sales (IHST)	Asset sales (IHST)	Money borrowed (IHST)	Money borrowed (IHST)	Net difference (IHST)	Net difference (IHST)
Assigned locked loan	0.566		-0.158		0.0294		0.618	
	(0.836)		(1.014)		(0.991)		(2.060)	
Assigned surprise unlocked loan	0.190		-1.319		-0.0759		0.467	
	(0.710)		(0.861)		(0.842)		(1.750)	
Assigned unlocked loan	0.956		0.0602		0.128		0.905	
	(0.665)		(0.807)		(0.789)		(1.639)	
Assigned any loan		0.698		0.698		0.0364		0.810
		(0.732)		(0.732)		(0.867)		(1.802)
Constant	10.55***	10.49***	4.831***	10.49***	9.274***	9.271***	-1.886***	-1.955**
	(0.290)	(0.347)	(0.352)	(0.347)	(0.344)	(0.411)	(0.714)	(0.854)
Outcome mean (level)	901450	901450	356959	356959	888500	888500	-344009	-344009
n	1852	1852	1852	1852	1852	1852	1852	1852

Note: Asset purchases, asset sales, and money borrowed are winsorized at the 99th percentile. The LATE measures the average treatment effect for compliers, using actual receipt of a school fee loan type (or any school fee loan) as the endogenous variable. "Net difference" records the difference between asset purchases and asset sales, minus money borrowed. Winsorizing takes place before IHST transformation. For 31 individuals who reported a source of a loan as ReadyPay, the amount of the school fee loan was added back into the total amount reported to have been borrowed. The above analysis uses the Intent to Treat (ITT). * $p < .10$, ** $p < .05$, *** $p < .01$

Table A.12: Household Balance Sheet Effects (ITT)

	Asset purchases (IHST)	Asset purchases (IHST)	Asset sales (IHST)	Asset sales (IHST)	Money borrowed (IHST)	Money borrowed (IHST)	Net difference (IHST)	Net difference (IHST)
Assigned locked loan	0.279		-0.0776		0.0145		0.304	
	(0.412)		(0.499)		(0.489)		(1.015)	
Assigned surprise unlocked loan	0.0981		-0.682		-0.0392		0.241	
	(0.367)		(0.444)		(0.436)		(0.904)	
Assigned unlocked loan	0.524		0.0330		0.0700		0.496	
	(0.364)		(0.441)		(0.433)		(0.898)	
Assigned any loan		0.307		-0.264		0.0160		0.356
		(0.321)		(0.389)		(0.381)		(0.792)
Constant	10.55***	10.55***	4.831***	4.831***	9.274***	9.274***	-1.886***	-1.886***
	(0.290)	(0.290)	(0.351)	(0.351)	(0.344)	(0.344)	(0.715)	(0.714)
Outcome mean (level)	901450	901450	356959	356959	888500	888500	-344009	-344009
P value from K-W H test	0.607		0.442		0.961		0.984	
P value from M-W U test		0.978		0.493		0.968		0.859
n	1852	1852	1852	1852	1852	1852	1852	1852

Note: Asset purchases, asset sales, and money borrowed are winsorized at the 99th percentile. The above analysis uses the Intent to Treat (ITT). "Net difference" records the difference between asset purchases and asset sales, minus money borrowed. Winsorizing takes place before IHST transformation. For 31 individuals who reported a source of a loan as ReadyPay, the amount of the school fee loan was added back into the total amount reported to have been borrowed. * $p < .10$, ** $p < .05$, *** $p < .01$

Table A.13: Household Balance Sheet Effects, calculated (semi-)elasticities (ITT)

	Asset purchases (IHST)	Asset sales (IHST)	Money borrowed (IHST)	Net difference (IHST)
Loan	0.359	-0.232	0.016	-0.314
	(0.437)	(0.299)	(0.388)	(0.565)

Note: Standard errors in parentheses. Asset purchases, asset sales, and money borrowed are winsorized at the 99th percentile. The above analysis uses the Intent to Treat (ITT) estimates to derive semi-elasticities. "Net difference" records the difference between asset purchases and asset sales, minus money borrowed. Winsorizing takes place before IHST transformation. For 31 individuals who reported a source of a loan as ReadyPay, the amount of the school fee loan was added back into the total amount reported to have been borrowed. Loan refers to the semi-elasticity calculated following the exact method from Bellemare and Wichman (2019), following arguments from Halvorsen and Palmquist (1980), Kennedy (1981) and Giles (1982). * $p < .10$, ** $p < .05$, *** $p < .01$

Table A.14: Tests of Lockout, Adverse Selection, and Moral Hazard, Risk (Interactions Model) (ITT)

	Lockout	Adverse Selection	Moral Hazard
On Loan Repayment at 150 days			
Treatment	0.10*	0.08**	0.01
	(0.05)	(0.04)	(0.05)
Treatment × Median risk or above	0.03	-0.09	0.12*
	(0.07)	(0.06)	(0.07)
Median risk or above	-0.16***	-0.16***	-0.25***
	(0.04)	(0.04)	(0.04)
Constant	0.65***	0.65***	0.73***
	(0.03)	(0.03)	(0.03)
On Loan Completion at 185 days			
Treatment	0.11*	0.07	0.04
	(0.06)	(0.05)	(0.06)
Treatment × Median risk or above	0.03	-0.07	0.10
	(0.09)	(0.07)	(0.09)
Median risk or above	-0.19***	-0.19***	-0.26***
	(0.05)	(0.05)	(0.05)
Constant	0.55***	0.55***	0.62***
	(0.04)	(0.03)	(0.04)
n	601	750	543

Note: Standard errors in parentheses. Loan repayment is measured by the cumulative proportion of the loan principal repaid. Loan completion describes whether the loan principal has been repaid. The above results display the Intent to Treat (ITT) analysis, which measures the average effect of assignment on loan repayment or loan completion. The analysis is run on the sample at the 150th day (for loan repayment) or 185th day (for loan completion) from origination for the Completed customer sample. Under "Lockout" where the subsample is those who were assigned Locked or Unlocked, "Treatment" captures the treatment effect of Locked. Under "Adverse Selection" where the subsample is those who were assigned Unlocked or Surprise Unlocked, "Treatment" captures the treatment effect of Surprise Unlocked. Under "Moral Hazard" where the subsample is those who were in assigned Surprise Unlocked and Locked, "Treatment" captures the treatment effect of Locked. "Median risk or above" is an indicator for whether the customer had their solar home system locked for 11 percent or more of its history by early May 2019, right before the start of the experiment. "×" represents an interaction. * $p < .10$, ** $p < .05$, *** $p < .01$

Table A.15: Tests of Lockout, Adverse Selection, and Moral Hazard, WTP (Interactions Model) (LATE)

	Lockout	Adverse Selection	Moral Hazard
On Loan Repayment at 150 days			
Treatment	0.11	0.01	0.10
	(0.07)	(0.06)	(0.07)
Treatment × Above median WTP	0.07	0.05	0.02
	(0.09)	(0.08)	(0.09)
Above median WTP	0.01	0.02	0.06
	(0.05)	(0.05)	(0.05)
Constant	0.58***	0.58***	0.59***
	(0.04)	(0.04)	(0.04)
On Loan Completion at 185 days			
Treatment	0.11	-0.01	0.12
	(0.09)	(0.07)	(0.09)
Treatment × Above median WTP	0.10	0.07	0.03
	(0.11)	(0.09)	(0.11)
Above median WTP	0.01	0.01	0.08
	(0.06)	(0.06)	(0.06)
Constant	0.47***	0.47***	0.46***
	(0.05)	(0.05)	(0.05)
n	468	595	437

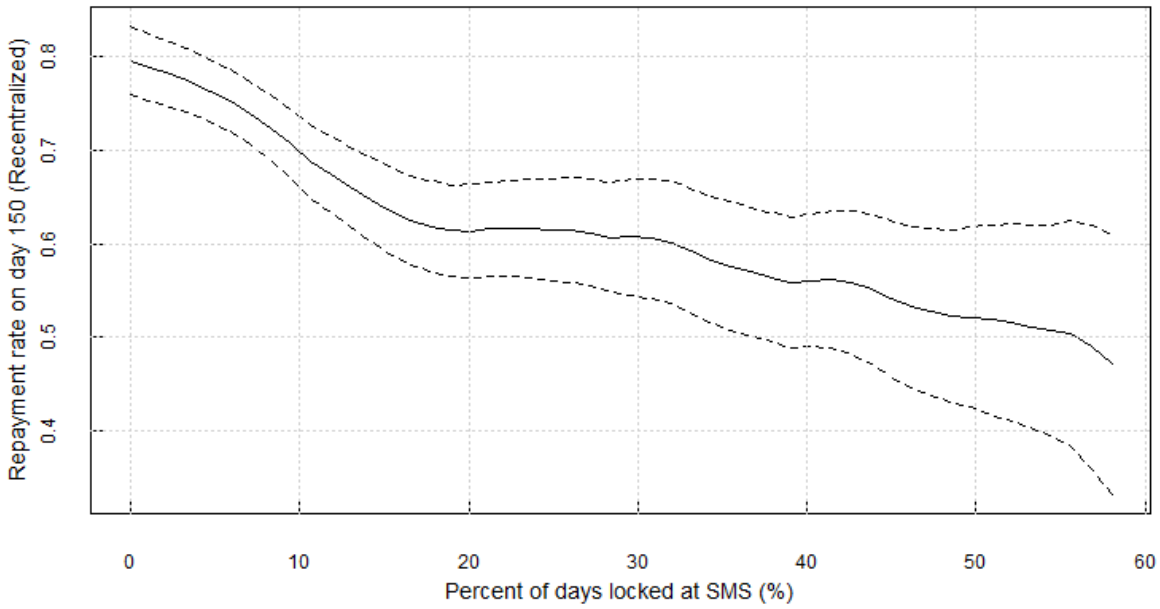
Note: Standard errors in parentheses. Loan repayment is measured by the cumulative proportion of the loan principal repaid. Loan completion describes whether the loan principal has been repaid. The above results display the Local Average Treatment Effect (LATE), which measures the average treatment effect on either loan repayment or loan completion for compliers, using the share of days in compliance as the endogenous variable (see the Appendix for Intent to Treat (ITT) results). The analysis is run on the sample at the 150th day (for loan repayment) or 185th day (for loan completion) from origination for the Completed customer sample. Under "Lockout" where the subsample is those who were assigned Locked or Unlocked, "Treatment" captures the treatment effect of Locked. Under "Adverse Selection" where the subsample is those who were assigned Unlocked or Surprise Unlocked, "Treatment" captures the treatment effect of Surprise Unlocked. Under "Moral Hazard" where the subsample is those who were in assigned Surprise Unlocked and Locked, "Treatment" captures the treatment effect of Locked. "Median WTP or above" is an indicator for whether the customer responded as willing to pay at least 3,000 Ugandan Shillings to unlock their hypothetically-locked solar home system the next day. "×" represents an interaction. * $p < .10$, ** $p < .05$, *** $p < .01$

Table A.16: Tests of Lockout, Adverse Selection, and Moral Hazard, WTP (Interactions Model) (ITT)

	Lockout	Adverse Selection	Moral Hazard
On Loan Repayment at 150 days			
Treatment	0.10	0.01	0.09
	(0.06)	(0.05)	(0.06)
Treatment × Median WTP or above	0.06	0.05	0.02
	(0.08)	(0.07)	(0.08)
Median WTP or above	0.02	0.02	0.07
	(0.05)	(0.05)	(0.05)
Constant	0.58***	0.58***	0.59***
	(0.04)	(0.04)	(0.04)
On Loan Completion at 185 days			
Treatment	0.09	-0.01	0.10
	(0.08)	(0.07)	(0.08)
Treatment × Median WTP or above	0.09	0.06	0.03
	(0.10)	(0.08)	(0.10)
Median WTP or above	0.02	0.02	0.08
	(0.06)	(0.06)	(0.06)
Constant	0.47***	0.47***	0.46***
	(0.05)	(0.05)	(0.05)
n	468	595	437

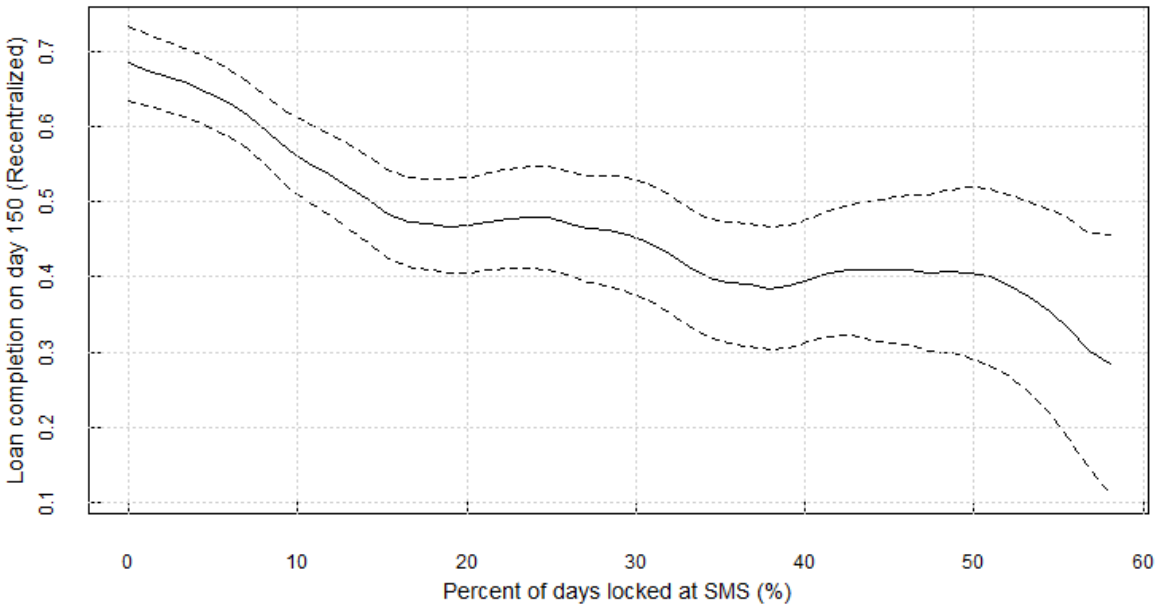
Note: Standard errors in parentheses. Loan repayment is measured by the cumulative proportion of the loan principal repaid. Loan completion describes whether the loan principal has been repaid. The above results display the Intent to Treat (ITT) analysis, which measures the average effect of assignment on loan repayment or loan completion. The analysis is run on the sample at the 150th day (for loan repayment) or 185th day (for loan completion) from origination for the Completed customer sample. Under "Lockout" where the subsample is those who were assigned Locked or Unlocked, "Treatment" captures the treatment effect of Locked. Under "Adverse Selection" where the subsample is those who were assigned Unlocked or Surprise Unlocked, "Treatment" captures the treatment effect of Surprise Unlocked. Under "Moral Hazard" where the subsample is those who were in assigned Surprise Unlocked and Locked, "Treatment" captures the treatment effect of Locked. "Median WTP or above" is an indicator for whether the customer responded as willing to pay at least 3,000 Ugandan Shillings to unlock their hypothetically-locked solar home system the next day. "×" represents an interaction. * $p < .10$, ** $p < .05$, *** $p < .01$

Figure A.1: Repayment by Percent of Days Locked on Day 150



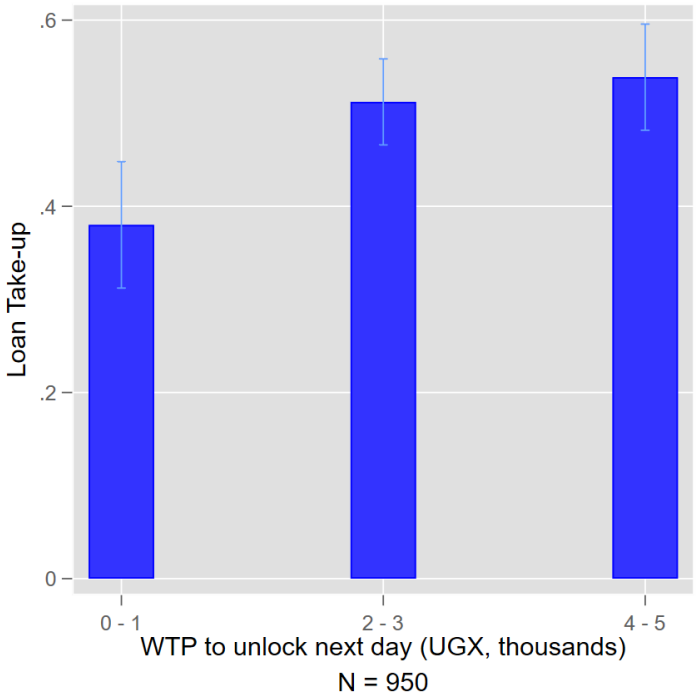
Note: 95% confidence intervals (displayed with dotted lines) are obtained via bootstrapping. Percent of days locked at SMS is trimmed at 1% and 99%. Repayment rate on day 150 is residualized to remove the effects of treatments and recentralized to the mean of the Locked group.

Figure A.2: Completion by Percent of Days Locked on Day 150



Note: 95% confidence intervals (displayed with dotted lines) are obtained via bootstrapping. Percent of days locked at SMS is trimmed at 1% and 99%. Loan completion on day 150 is residualized to remove the effects of treatments and recentralized to the mean of the Locked group.

Figure A.3: Loan take-up by willingness to pay



Note: This figure covers the sample of 952 individuals, of which 344 are treated with Locked loans and 608 are treated with Unlocked loans. Individuals treated with Surprise unlocked loans are excluded from this figure. Individuals with willingness to pay to unlock next day being 0 or 1,000 UGX are in the first group, being 2,000 or 3,000 UGX in the second group, and being 4,000 or 5,000 in the third group. The average loan take-up by willingness to pay is plotted and 95% confidence intervals are along with the bars.