Optimal Arrangements for Distribution in Developing Markets

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Motivation

Household investment in a number of "basic" technologies appears to have large benefits for developing economies.

- Mosquito nets
  - Malaria kills $\approx$ 1M people each year
- Fertilizer
  - Key factor explaining lack of agricultural growth
- Water filters
  - Drinking water is considered a leading culprit for disease.
- Solar lights, efficient cookstoves, etc.

Yet the growth of private markets and rate of adoption has been slow

- The "product adoption puzzle"

One Example

About 590 million Africans live off the grid. Most of them rely on flame-based lamps powered by fossil fuels like kerosene. The light from these lamps is dim and comes with significant health and financial costs. A kerosene lamp may cost less than \$5, but fuel averages about \$57 per year. Sub-Saharan Africans burn about \$10 billion annually on kerosene, and worldwide, kerosene costs people without electricity \$36 billion.

—Study by the World Bank

The Solution

The Economics of Going Solar

- Typical household spends \$2 on kerosene per week
- Plus additional time and money to charge cell phone
- \$25 Firefly Mobile
  - Saves \$1.50 per week (conservatively)
  - Bond with coupon of 6% **per week**
  - Lifespan of $\approx$ 2 years
  - IRR $>$ 300%

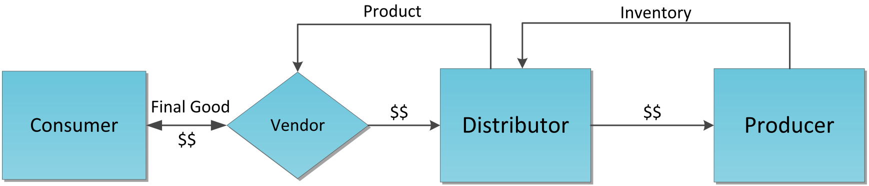
NB. Ignores health benefits.

What hinders growth? Why the market failure?

Markets for these goods are not developing very fast...

- If solar lights are so great, why are they not being produced and sold in massive quantities?

What hinders growth? Why the market failure?



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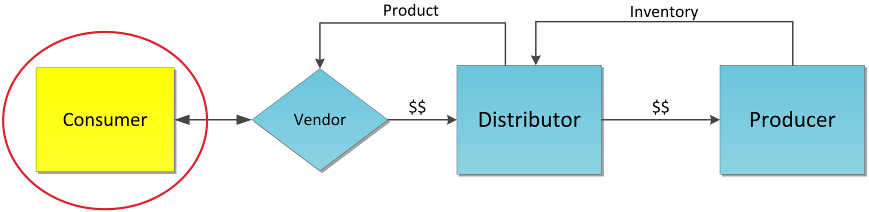
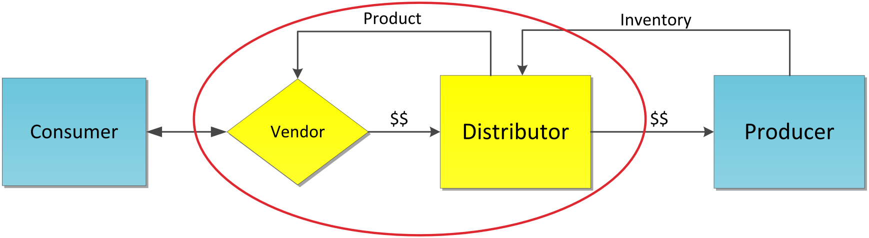


Existing Literature: Demand-side frictions

- Credit/liquidity constraints
- Lack of information about benefits or quality
- Present bias
- Risk aversion

What hinders growth? Why the market failure?



Our Focus: Supply-side frictions

- Credit/liquidity constraints
- Limited contract enforcement
- Uncertainty or aversion to experimentation
- Lemons problem

Addressing demand side can have large effects

To address demand-side frictions:

- “Novel” offer (Levine and Cotterman, 2012)
  - Time payments: to ease credit constraints
  - Free trial: provides “experience”
  - Right to return: reduces risk
- Results looks promising
  - In randomized trial of 1,800 households in Kampala
  - Retail offer: 4% of consumers bought a stove.
  - Novel offer: 45% uptake, 97% of payments received.
- How to scale up?

Objectives

1. Develop a simple model to capture vendor/distributor relationship
   - Use the model to derive "optimal" arrangements
2. Use framework to distinguish between potential impediments.
   - Develop several testable hypothesis
3. Test both the optimal arrangement and hypotheses in an experimental setting

Key Features of the Environment

- "Principal" wants to hire an "agent" to sell some good
  - Non-profit organization with limited budget, or
  - Profit maximizing firm
- Agent has no access to capital
  - Enjoy limited liability
- Not all end consumers can pay up front
  - Some may miss payments or default
  - Sales revenue is stochastic
- Sales are not verifiable, contracts are not enforceable.
  - Agent can abscond with inventory or misreport sales
  - Arrangement must be incentive compatible

Preview of Results

1. Theoretical
    - Optimal arrangement can be implemented with
        - An initial "small" endowment of the good
        - Fixed price for all future units
    - Structure is optimal for both profit-maximizing firms and budget-constrained non profit organizations
2. Experimental
    - Optimal arrangement increased sales by 3-4x
    - Credit constraints and consumer uncertainty both important
    - Sales growth lower than model predicted
        - Difficulty saving
        - Failure of the "credit chain"

Related Theoretical Literature

Dynamic Contracting

- Abuquerque and Hopenhayn (2004), DeMarzo and Fishman (2007a), DeMarzo and Sannikov (2006)

With Investment

- Thomas and Worrall (1994), Quadrini (2004), Clementi and Hopenhayn (2006), DeMarzo and Fishman (2007b), Biais et al (2010), DeMarzo et al (2012)

Self Enforcing

- Baker et al. (2002), Levin (2003)

Our contribution

1. An application with a simple implementation
2. Workhorse models in dynamic contracting useful for problems in development economics.

The Model

- Principal (P) and an agent (A) can interact repeatedly over an infinite horizon: $t = 0, 1, 2, \ldots$
- P can produce good at marginal cost of c.
- A has access to a market in which she can sell goods up to $\bar{k}$ units each period at a price $p \sim F$ on $[p_{\min}, p_{\max}]$ with $\mathbb{E}(p) > c$.
- A has no initial capital (i.e., cannot pay cash for goods) and enjoys limited liability.
- A can walk away at any time.

Timing and Payoffs

At the beginning of each period, t:

- P gives A some amount of goods, k_t
- A sells the goods, realizes cash flow $p_t k_t$ and reports $\hat{p}_t$ to P
- A makes a transfer payment of T_t to P and consumes the remainder $p_t k_t - T_t$
- Move to next period, repeat...

Both P and A are risk neutral and maximize expected discounted payoff

- A is weakly more impatient ($\delta_A \leq \delta_P$)

First-Best Arrangement

Absent frictions (and $\delta_A = \delta_P$), the P-optimal arrangement involves:

- Efficient Investment: $k_t = \bar{K}$
- Full Extraction: $T_t = p_t k_t$

Two frictions make this infeasible

- Enforcement: The agreement is not self-enforcing, the agent would rather run away with k_t units of inventory.
- Information: If investment is always efficient and transfer is fully extracting, the agent should always report $p_{\min}$.

Self-Enforcing Arrangements

- A pure strategy for P is a sequence of functions $\sigma^P = \{k_t\}$:
    - Specify the quantity given to A as a function of history
- A pure strategy for A is a sequence $\sigma^A = \{\hat{p}_t, T_t\}$:
    - Specify reports and transfers as a function of the A-history.
- An arrangement is *self-enforcing* if (σ^P, σ^A) constitute an equilibrium of the game.
- Focus on Pareto efficient equilibria, parameterized by A's continuation value v.

Principal's Objective and relation to NGO Problem

- Principal's objective is

$$\max \sum_{t=0}^{\infty} \delta_P^t (T_t - ck_t), \tag{P-obj}$$

subject to some constraints (C).

- Consider instead an NGO who attaches social value Δ_S to each unit distributed and wants to maximize total social surplus

$$\max \sum_{t=0}^{\infty} \delta^t k_t \Delta_S$$

subject to constraints (C) as well as a budget constraint

$$\sum_{t=0}^{\infty} \delta_P^t (ck_t - T_t) \leq B$$

Relation to NGO Problem

- The dual of the NGO problem is to minimize the total cost of operation

$$\min \sum_{t=0}^{\infty} \delta_P^t (ck_t - T_t) \tag{CMP}$$

subject to constraints (C) and achieving some level of social surplus

$$\Delta_S \sum_{t=0}^{\infty} \delta_P^t k_t \geq S$$

- Naturally, (CMP) is equivalent to

$$\max \sum_{t=0}^{\infty} \delta_P^t (T_t - ck_t). \tag{P-obj}$$

Recursive Formulation

$$\Pi(v) = \max_{K,T,V} E_p \left[T(p,v) - \gamma K(v) + \delta_P \Pi(V(p,v)) \right]$$

subject to

$$T(p,v) \leq pK(v) \qquad \text{(Liquidity)}$$

$$K(v) \in [0, \bar{k}] \qquad \text{(Capacity)}$$

$$\delta_A V(p,v) - T(p,v) \geq \delta_A V(\hat{p},v) - T(\hat{p},v) \qquad \text{(IC)}$$

$$\delta_A V(p,v) - T(p,v) \geq v_{out} = 0 \qquad \text{(PC)}$$

$$\mathbb{E}[pK(v) - T(p,v) + \delta_A V(p,v)] = v \qquad \text{(PK)}$$

Solution to Principal's Problem

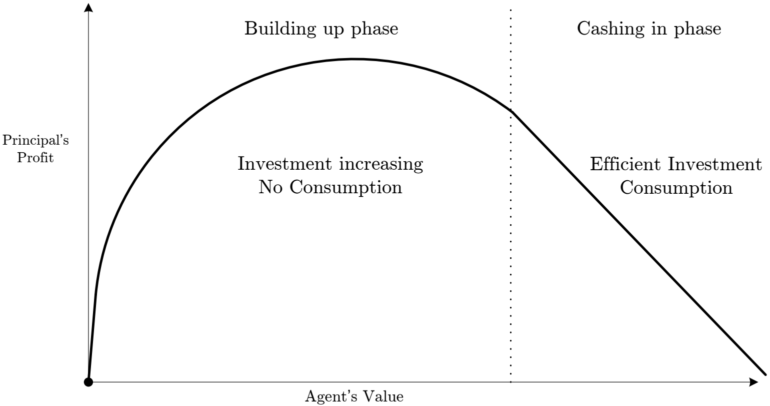
Suppose that there is no uncertainty: $p_{\min} = p_{\max} = \bar{p}$

- No information friction $\implies$ can ignore (IC) constraint
- (PC) and (PK) require

$$\bar{p}K \leq v,$$

  otherwise agent will abscond.
  - Principal must (inefficiently) restrict inventory level for low v
- Linearity of preferences and technology $\implies$ solution is "bang-bang"

Optimal Arrangements without Information Frictions



Implementing the Optimal Arrangement

Proposition

The optimal agreement can be implemented with

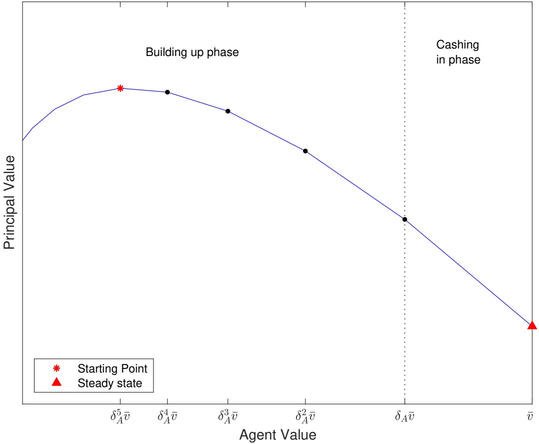
- *An initial endowment* $k_0^* < \bar{K}$
- *A fixed price* $q^* < \bar{p}$

P gives A the initial endowment and charges the fixed price for all future units at which A can purchase units of the good.

Intuition

- Endowment eases credit constraint
- Discounted price incentivizes reinvestment

Dynamics



Dynamics begin at the red asterisk and moves rightward until agent's value reaches $\delta_A \bar{V}$ above which investment is efficient and the agent consumes.

Starting Small

- $N^* \equiv \min\{t : k_t = \bar{k}\}$ is the "time-to-capacity"
- $\gamma \equiv \frac{\delta_P}{\delta_A}$ is the agent's relative impatience
- $\mu \equiv \frac{\bar{p}-c}{\bar{p}}$ is the profit margin

Proposition

The optimal initial endowment is $k_0^* = \delta_A^{N^*} \times \bar{k}$, where

- *If $\delta_A = \delta_P$ then $N^* = \left\lceil \frac{1-\mu}{\mu} \right\rceil$*
- *If $\delta_A < \delta_P$ then*

$$N^* = \left\lceil \frac{\log\left(\frac{\mu}{1+\gamma(\mu-1)}\right)}{\log(\gamma)} \right\rceil$$

Starting Small

Corollary

The size of the optimal initial endowment is

(i) *is increasing in the profit margin*

(ii) *decreasing in the relative impatience of the agent*

Implication: Starting small is particular important when

- Profit margin is low (or even negative)
- Agent is relatively impatient

Risky Cash Flows and Information Frictions

- When $p_{\min} \neq p_{\max}$, P must provide incentives for truthful reporting:
  - If agent reports high $\hat{p}_t$, P *rewards* A with higher future k
  - If agent reports low $\hat{p}_t$, P *punishes* A with lower future k
- Notice, this features is already achieved by the fixed-price arrangement
  - When A realizes high $\hat{p}_t$, has more money to buy k_{t+1}
- But may also be optimal to save for $k_{t+2}, k_{t+3}, \ldots$ in case p_{t+1} is low

With Information Frictions: Implementation

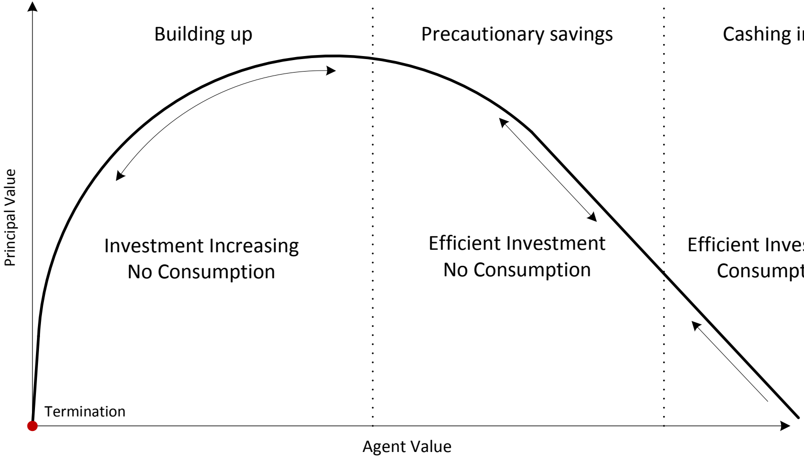
Proposition

Suppose cash flows are risky and privately observed by the agent. The optimal agreement can be implemented with:

- *An initial endowment* k_0^*
- *A fixed price* q_0^*
- *A savings account with return* $1/\delta_A$

P *gives* A *the initial endowment, charges the fixed price for all future units, and allows* A *to deposit/withdraw from the savings account.*

Dynamics with precautionary savings



Optimal arrangement with risky cash flows and precautionary savings.

More Intuition

Testable hypothesis

Model assumes vendors have no wealth or access to credit

- Hence, the need to provide an initial endowment

Hypothesis 1: Credit Constraints

If the agent has sufficient wealth or access to credit then performance of arrangement should not depend on the size of the initial endowment.

- By varying the size of the initial endowment, we can evaluate the extent to which credit constraints are relevant.

Testable hypothesis

Model assumes vendors are not risk averse nor "pessimistic" about profitability

- No need to provide additional incentives to reinvest

Hypothesis 2: Vendor Uncertainty

If the vendor is risk averse or pessimistic about the ability to sell the good for a profit then providing the "right to return" unsold units should improve the performance of the arrangement.

Testable hypothesis

Model takes household demand as given/fixed:

- But, we know demand-side frictions are important...
- Credit constraints, uncertainty, lemons problem, risk-aversion etc.

Hypothesis 3: Consumer Uncertainty

If consumers are uncertain about quality/benefits or liquidity constrained then providing agent with a "loaner" designated to provide customers with a free-trial period before their purchase should increase the performance of the arrangement.

- In theory, agent could do this on her own. In practice, most were not willing to.

Field Experiment

Objectives:

1. Test hypothesis of regarding factors inhibiting market development
2. Evaluate the performance of the optimal arrangement

Background

- Partnership with BRAC
- Recruited vendors from BRAC network of CHPs across 8 branches in rural Uganda
  - Branch has 4 zones,
  - Zone has 10+ MF meetings
  - 20+ women per MF meeting
  - We recruited one women per MF meeting
    - Geographically dispersed, catchment area $\approx$ 200 households
- Recruitment meeting: presentation/training
  - Opportunity to buy light on credit: experience + screening

Experimental design

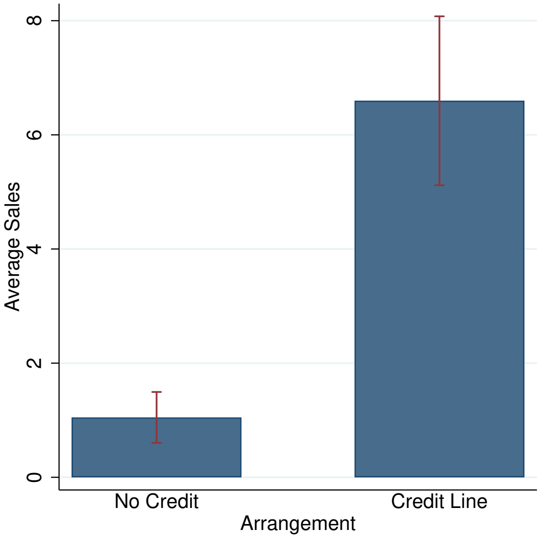
Recruits were offered an arrangement

- All arrangements gave vendors option to buy lights at wholesale price ($20)
  - Consistent with $\delta_A = 0.85$
- Three orthogonal randomizations (2 x 2 x 2)
  1. Trade credit (up to 4 lights)
     - Consistent with $\delta_P = 0.98$, $\bar{K} = 10$
  2. Right to return
  3. Loaner light
- Monthly orders and restocking
  - Delivered to BRAC branch
  - Vendors placed orders via mobile phone
- Tracked sales for 12 months

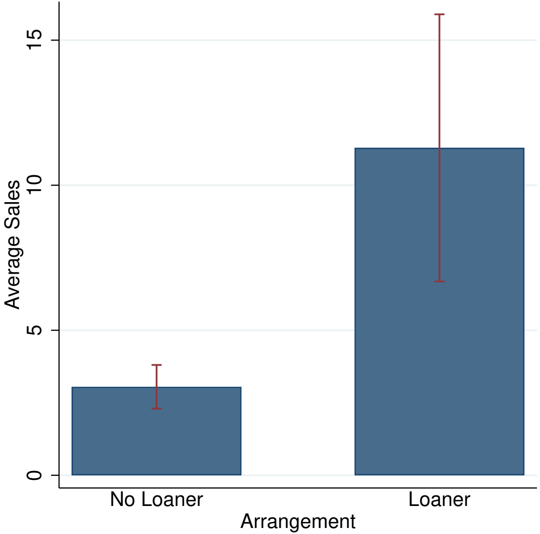
Vendor characteristics

	None	Primary	Secondary	
Education	28%	60%	12%	
	Retail	Agriculture	Livestock	Other
Occupation	51%	40%	13%	40%
	Mean	Median	Std Dev	
Age	39.1	38	9.55	
Experience	9.4	6	10.2	
Work hours/day	8.46	8	3.98	
Children	4.91	5	2.74	
Residency	17.8	15	13.3	
Travel time to BRAC	58.3	60	37.7	
Kerosene expenditure				
Pre-solar	3,264	3,000	2,799	
Post-solar	305	0	826	
Married	70%			
Own mobile phone	98%			
Use SMS	47%			
Use Mobile Money	83%			

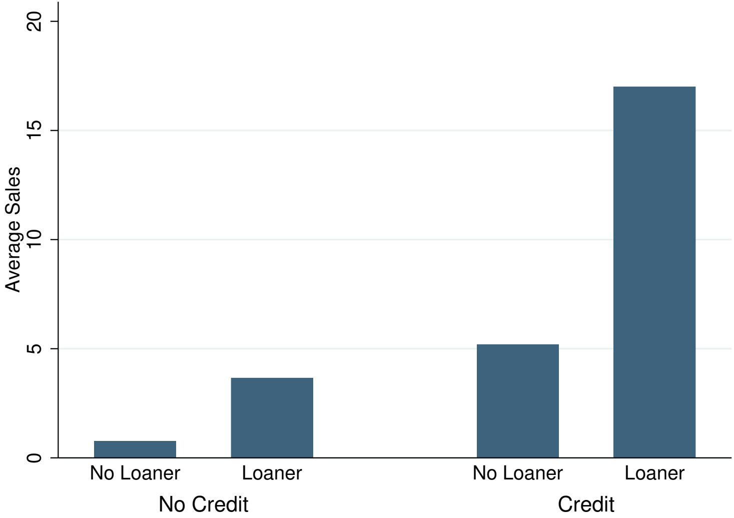
Credit constraints



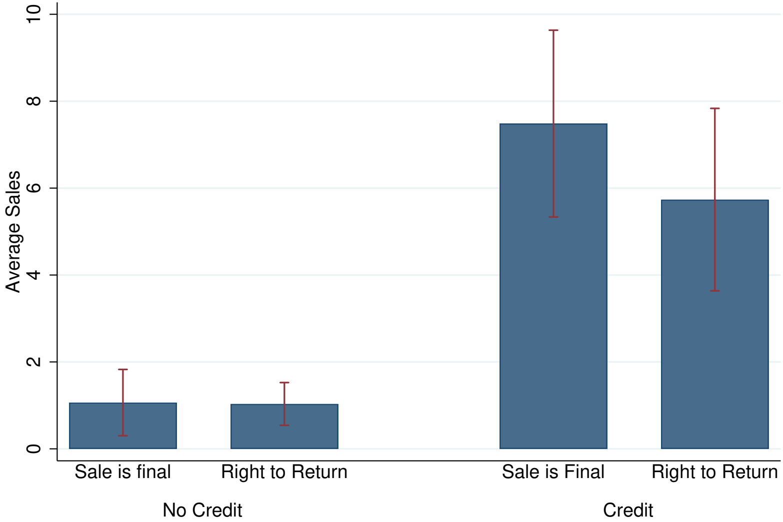
Consumer uncertainty / lack of information



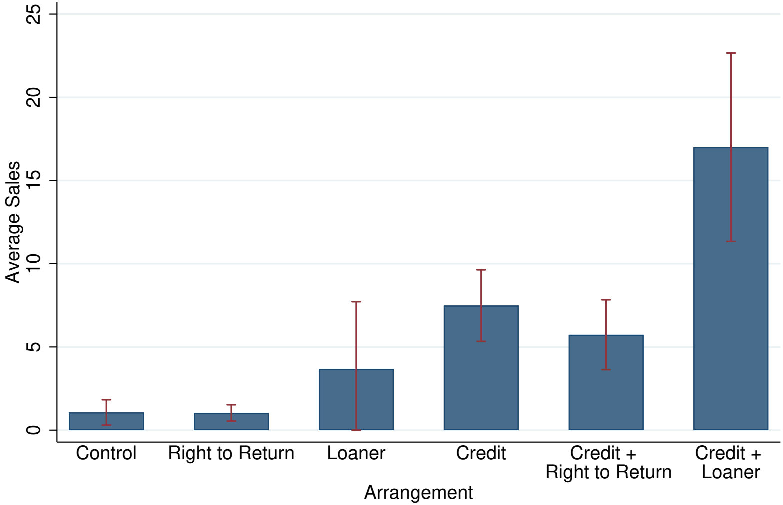
Consumer uncertainty / lack of information



Vendor uncertainty / lack of information



Comparison across offer types



Regression Equation

$$\log(1 + \text{total sales}_i) = \alpha + \gamma \times \text{credit}_i \\ + \beta \times \text{loaner}_i \\ + \delta \times \text{right to return}_i + \epsilon_i$$

- Vendor is unit of observation
- Standard errors clustered at the branch level

Predicting Sales

	(1)	(2)	(3)	(4)	(5)	(6)
Credit	1.086***	1.078***	1.087***	1.078***	1.371***	1.342***
	(5.11)	(5.03)	(5.13)	(5.05)	(4.98)	(4.65)
Loaner		1.232**		1.227**	1.238**	0.776
		(2.77)		(2.75)	(2.81)	(1.61)
Right to Return			-0.122	-0.100	-0.380*	-0.373*
			(-1.45)	(-1.15)	(-2.28)	(-2.32)
Right x No Credit					0.582*	0.538*
					(2.34)	(1.99)
First wave						0.690**
						(2.75)
R^2	0.266	0.407	0.269	0.409	0.428	0.512
N	129	129	129	129	129	129

t-statistics in parenthesis

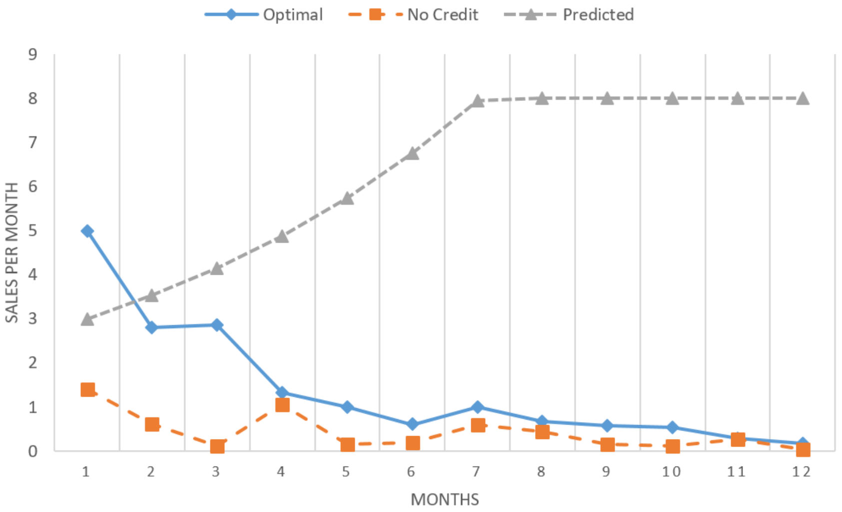
Survey Responses: Marketing and Sales Strategies

- Main Advantage of Solar?
  - Save Money (51%), Safety (28%), Health (2%)
- Customer Base?
  - Door to Door (62%), Friends and family (38%), Church (32%), BRAC group (17%)
- Retail offer to customers?
  - Cash (70%), Installments (11%), Layaway (13%), ROSCA (6%)
- Demand-side barriers?
  - Money (55%), Product knowledge (26%), Past bad experience (28%)

Summary of Findings

- Credit constraints matter
  - Optimal arrangement increased sales by 3-4x
- Consumer uncertainty/information also important
  - Providing "loaner" light had significant positive effect
- Vendor uncertainty/information appears less important
- Growth rates lower than predicted by the model
  - Average vendor: selling 1.5 lights/month after 4 months

Sales dynamics



What Inhibited Growth?

1. Difficulty saving
   - Vendors noted difficulty retaining cash from sales until the next order, usually a few weeks away
   - Saving is notoriously difficult in rural Africa
     - e.g., Karlin et al. (2014)
2. Failure of the "credit chain"
   - Most vendors were unwilling to offer an installment plan to customers (Despite our encouragement to do so)
   - 70% required customers to pay for light in full before ordering
   - 55% acknowledge that $$ was the primary demand-side barrier

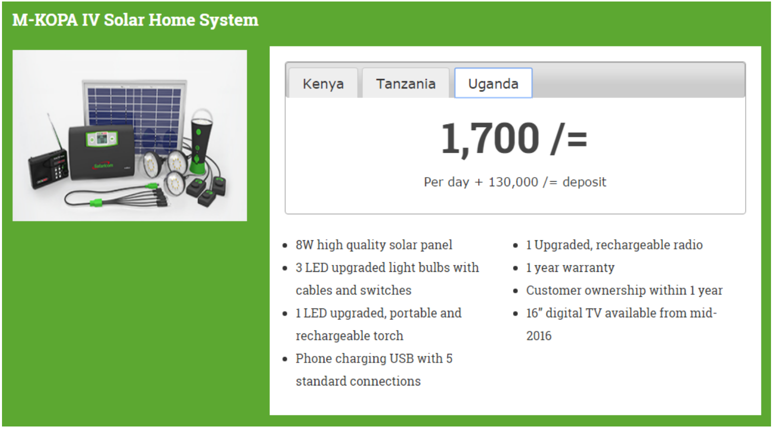
Is Technology the Answer?

1. Mobile Money
   - Payments go directly from consumer to producer
   - No need for vendor to handle cash
   - Both mobile phones and mobile money are widespread
2. A "kill" switch (+ PAYG)
   - Turns system into a "brick"
   - System won't work if consumer doesn't pay
   - No incentive for vendor to abscond with inventory

Combining these two features effectively solves:

- Frictions in our model
- Inability to save (for both consumers and vendors)
- Credit chain failure

The M-Kopa Model



- \$35 down + \$0.50/day for one year $\implies$ PV = \$150-185
  - Adding kill switch basically doubles retail price

So, is Technology the Answer?

M-Kopa has sold over 500,000 systems in East Africa and is growing rapidly

- Evidence that these frictions are really first order!
- But, it is expensive....
- Kill switch likely prohibitively costly for products that do not run on electricity
  - e.g., cookstoves, water filters, malaria nets

Next question: how far can we get with mobile money+dynamic incentives, but without the (expensive) kill switch?

Why have precautionary savings?

- A 's consumption is delayed in order to insure against negative shocks.
  - e.g., $p_t = p_{\min}$ for $t = 1, 2, 3, \ldots$
- However, there is a cost associated with precautionary savings
  - A is relatively impatient (unless $\delta_A = \delta_P$)
- Optimal arrangement trades off insurance motive vs relative impatience
  - For $\delta_A << \delta_P$, no precautionary savings
  - For $\delta_A = \delta_P$ and p_t sufficiently risky, precautionary savings until P's participation constraint binds.

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