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Lecture notes

Applications of the theory of incentives in development economics

Textbook and journal articles:

Chapters 2 and 4 of "The Theory of Incentives" by J. Laffont and D. Martimort, 2002

Levin J. 2003. "Relational Incentive Contracts." American Economic Review

Holmstrom, B. 1982. Moral hazard in teams. Bell Journal of Economics 13: 324–340.

Saenger, C., M. Torero, and M. Qaim. 2014 "Impact of Third-party Contract Enforcement in Agricultural Markets—A Field Experiment in Vietnam." American Journal of Agricultural Economics

Many economic problems are a matter of incentives:

- incentives to work hard, invest, save, produce good quality products, study, teach, etc

How to provide appropriate incentives in organizations is a central question

Incentive problems arise when a principle delegates a task to an agent

- imperfect information about the agent
- conflicting objectives of the principal and the agent

Agent has private information about his

actions: **moral hazard**

cost or valuation: **adverse selection**

Agent and Principal share information but it cannot be observed by a third party: **non-verifiability**

Examples:

regulator and a firm that know its production costs

seller knows the value of a product but buyer does not: insurance companies buys risks

consumers know their valuations but the firm does not: price discrimination

government taxation of wage earners who differ in abilities and efforts

I. Adverse Selection in a Principal-Agent Relationship

1. Technology, Preferences, Information

Principal (P) asks agent (A) to produce $q \geq 0$ units

$S(q), S' > 0, S'' < 0, S(0) = 0$ - principal's value of q units

$C(q,\theta) = F + q\theta$ - agent's production cost

$\theta \in \{\underline{\theta}, \overline{\theta}\}$ - cost parameter known to the agent but unknown to the principal

$0 < \underline{\theta} < \overline{\theta}$

$\Pr(\theta = \underline{\theta}) = \nu \in (0,1)$ is common knowledge

Principal can offer transfer t to the agent

2. Contracting variables

Only variables q and t are observable and *verifiable*

$A = \{(q,t) : q \geq 0, -\infty < t < \infty\}$ is the set of feasible allocations (can be endogenous)

3. Timing

1. A observes his type θ
2. P offers a contract: a menu of transfers for different quantities $\{(q,t)\}$
3. A accepts or refuses the contract
4. The contract is executed

Benchmark: Complete information about cost (Efficient Allocation)

Solution without delegation: $\max_q S(q) - \theta q - F$

$S'(\underline{q}^*) = \underline{\theta}$

$S'(\overline{q}^*) = \overline{\theta}$

$\underline{W}^* = S(\underline{q}^*) - \underline{\theta}\underline{q}^* - F > \overline{W}^* = S(\overline{q}^*) - \overline{\theta}\overline{q}^* - F > 0$ (all types should produce)

$S(\underline{q}^*) - \underline{\theta}\underline{q}^* > S(\overline{q}^*) - \underline{\theta}\overline{q}^* > S(\overline{q}^*) - \overline{\theta}\overline{q}^*$ => $\underline{q}^* > \overline{q}^*$ (low-cost type should produce more)

Implementing the First-Best Allocation

$F = 0$ and agent's reservation utility is zero

$\max_q S(q) - \theta q$ subject to participation constraints:

$t - C(q,\theta) = t - \theta q \geq 0$

$t = C(q,\theta)$ is the optimal transfer (P gets $S(q) - t$ and A gets $t - C(q,\theta)$)

$\underline{t}^* = \underline{\theta}\underline{q}^*$ and $\underline{q}^*$ if $\theta = \underline{\theta}$ (contract $(\underline{q}^*, \underline{t}^*)$)

$\bar{t}^* = \bar{\theta}\bar{q}^*$ and $\bar{q}^*$ if $\theta = \bar{\theta}$ (contract $(\bar{q}^*, \bar{t}^*)$)

This solution is called the First Best: delegation is costless to Principal

Private information about cost

Incentive compatibility

Suppose P offers a menu $\{(\underline{q}^*, \underline{t}^*), (\bar{q}^*, \bar{t}^*)\}$ and lets A choose

If $\theta = \bar{\theta}$: $\underbrace{\bar{\theta}\bar{q}^*}_{\bar{t}^*} - \bar{\theta}\bar{q}^* = 0 > \underbrace{\underline{\theta}\underline{q}^*}_{\underline{t}^*} - \bar{\theta}\,\underline{q}^*$ (high cost chooses low output option)

If $\theta = \underline{\theta}$: $\underbrace{\underline{\theta}\underline{q}^*}_{\underline{t}^*} - \underline{\theta}\underline{q}^* = 0 < \underbrace{\bar{\theta}\bar{q}^*}_{\bar{t}^*} - \underline{\theta}\bar{q}^*$ (low cost also chooses low output option)

A menu of contracts $\{(\underline{q}, \underline{t}), (\bar{q}, \bar{t})\}$ is incentive compatible if simultaneously

- high cost type prefers $(\bar{q}, \bar{t})$ to $(\underline{q}, \underline{t})$: $\bar{t} - \bar{\theta}\bar{q} \geq \underline{t} - \bar{\theta}\,\underline{q}$

- low cost type prefers $(\underline{q}, \underline{t})$ to $(\bar{q}, \bar{t})$: $\underline{t} - \underline{\theta}\underline{q} \geq \bar{t} - \underline{\theta}\bar{q}$

Recall participation constraints:

- high cost type prefers to accept $(\bar{q}, \bar{t})$: $\bar{t} - \bar{\theta}\bar{q} \geq 0$

- low cost type prefers to accept $(\underline{q}, \underline{t})$: $\underline{t} - \underline{\theta}\underline{q} \geq 0$

A menu of contracts is incentive feasible if both IC and IR constrains are satisfied

Extreme menus

Bunching or Pooling Contracts: $\{(\underline{q},\underline{t}),(\bar{q},\bar{t})\}=\{(q,t),(q,t)\}$ (which constraint is the hardest to satisfy?)

Shut-Down of High-Cost Type: $\{(\underline{q},\underline{t}),(\bar{q},\bar{t})\}=\{(q,t),(0,0)\}$ (which constraint is the hardest to satisfy?)

Two more observations before solving for the optimal contract:

1. Let us add IC constraints:

$$\bar{t}-\bar{\theta}\bar{q}\geq \underline{t}-\bar{\theta}\underline{q}$$

$$\underline{t}-\underline{\theta}\underline{q}\geq \bar{t}-\underline{\theta}\bar{q}$$

=> $\bar{t}-\bar{\theta}\bar{q}+\underline{t}-\underline{\theta}\underline{q}\geq \underline{t}-\bar{\theta}\underline{q}+\bar{t}-\underline{\theta}\bar{q}$ => $(\bar{\theta}-\underline{\theta})\underline{q}\geq(\bar{\theta}-\underline{\theta})\bar{q}$ => $\underline{q}\geq\bar{q}$ (**implementability condition**)

2. **Information rent** (incremental payoff due to private information)

$\bar{U}=\bar{t}-\bar{\theta}\bar{q}$ - information rent of high-cost type

$\underline{U}=\underline{t}-\underline{\theta}\underline{q}$ - information rent of low-cost type

Under complete information, agents get no benefit from the relationship

$$\bar{U}^*=\underbrace{\bar{\theta}\bar{q}^*}_{\bar{t}^*}-\bar{\theta}\bar{q}^*=0$$

$$\underline{U}^*=\underbrace{\underline{\theta}\underline{q}^*}_{\underline{t}^*}-\underline{\theta}\underline{q}^*=0$$

Under incomplete information, low-cost type can pretend that his cost is high:

$\bar{t}-\underline{\theta}\bar{q}=\bar{t}-\bar{\theta}\bar{q}+\bar{\theta}\bar{q}-\underline{\theta}\bar{q}=\bar{U}+(\bar{\theta}-\underline{\theta})\bar{q}>0$ if $\bar{q}>0$

Principal's problem (recall P does not know the cost parameter and is risk-neutral)

$$\max_{(\underline{q},\underline{t}),(\bar{q},\bar{t})} \upsilon\left(S(\underline{q})-\underline{t}\right)+(1-\upsilon)\left(S(\bar{q})-\bar{t}\right)$$

subject to

$$\bar{t}-\bar{\theta}\bar{q}\geq 0$$

$$\underline{t}-\underline{\theta}\underline{q}\geq 0$$

$$\bar{t}-\bar{\theta}\bar{q}\geq \underline{t}-\bar{\theta}\,\underline{q}$$

$$\underline{t}-\underline{\theta}\underline{q}\geq \bar{t}-\underline{\theta}\bar{q}$$

Let us rewrite this problem in terms of the Principle choosing the agents' utilities:

From $\bar{U}=\bar{t}-\bar{\theta}\bar{q}$ and $\underline{U}=\underline{t}-\underline{\theta}\underline{q}$ we get: $\bar{t}=\bar{U}+\bar{\theta}\bar{q}$ and $\underline{t}=\underline{U}+\underline{\theta}\underline{q}$:

$$\max_{\underline{q},\bar{q},\underline{U},\bar{U}} \underbrace{\upsilon\left(S(\underline{q})-\underline{\theta}\underline{q}\right)+(1-\upsilon)\left(S(\bar{q})-\bar{\theta}\bar{q}\right)}_{\text{Expected Social Surplus}}-\underbrace{\left(\upsilon\underline{U}+(1-\upsilon)\bar{U}\right)}_{\text{Expected Information Rent}}$$

subject to

$$\bar{U}\geq 0$$

$$\underline{U}\geq 0$$

$$\bar{U}\geq \underline{t}-\bar{\theta}\,\underline{q}=\underline{t}-\underline{\theta}\underline{q}+\underline{\theta}\underline{q}-\bar{\theta}\,\underline{q}=\underline{U}-(\bar{\theta}-\underline{\theta})\underline{q}$$

$$\underline{U}=\underline{t}-\underline{\theta}\underline{q}\geq \bar{t}-\underline{\theta}\bar{q}=\bar{t}-\bar{\theta}\bar{q}+\bar{\theta}\bar{q}-\underline{\theta}\bar{q}=\bar{U}+(\bar{\theta}-\underline{\theta})\bar{q}$$

The solution to this problem is called Second Best (what makes the principle different from the Social Planner?)

What are the binding constraints? Argue that the problem reduces to

$$\max_{\underline{q},\bar{q},\underline{U},\bar{U}} \underbrace{\upsilon\left(S(\underline{q})-\underline{\theta}\underline{q}\right)+(1-\upsilon)\left(S(\bar{q})-\bar{\theta}\bar{q}\right)}_{\text{Expected Social Surplus}}-\underbrace{\left(\upsilon\underline{U}+(1-\upsilon)\bar{U}\right)}_{\text{Expected Information Rent}}$$

subject to

$$\bar{U}=0$$

$$\underline{U}\geq 0$$

$$\bar{U}=0>\underline{U}-(\bar{\theta}-\underline{\theta})\underline{q}=(\bar{\theta}-\underline{\theta})\bar{q}-(\bar{\theta}-\underline{\theta})\underline{q}=(\bar{\theta}-\underline{\theta})(\bar{q}-\underline{q})$$

$$\underline{U}=(\bar{\theta}-\underline{\theta})\bar{q}$$

Substituting the binding constraints into the objective function yields

$$\max_{\underline{q},\bar{q}} \underbrace{\upsilon\left(S(\underline{q})-\underline{\theta}\underline{q}\right)+(1-\upsilon)\left(S(\bar{q})-\bar{\theta}\bar{q}\right)}_{\text{Expected Social Surplus}}-\underbrace{\upsilon(\bar{\theta}-\underline{\theta})\bar{q}}_{\text{Expected Information Rent}}$$

The first-order conditions are

$$\underbrace{\upsilon(S'(\underline{q}^{SB})-\underline{\theta})}_{\text{Marginal Expected Social Surplus}}-\underbrace{0}_{\text{Marginal Expected Information Rent}}=0\text{, or } S'(\underline{q}^{SB})=\underline{\theta}$$

$$\underbrace{(1-\upsilon)(S'(\bar{q}^{SB})-\bar{\theta})}_{\text{Marginal Expected Social Surplus}}-\underbrace{\upsilon(\bar{\theta}-\underline{\theta})}_{\text{Marginal Expected Information Rent}}=0\text{, or } S'(\bar{q}^{SB})=\bar{\theta}+\frac{\upsilon}{1-\upsilon}(\bar{\theta}-\underline{\theta})$$

Low-cost agent produces the efficient output $\underline{q}^{SB}=\underline{q}^{*}$

High-cost agent produces too little $\bar{q}^{SB}<\bar{q}^{*}$

Low-cost agent gets a positive information rent $\underline{U}^{SB}=(\bar{\theta}-\underline{\theta})\bar{q}^{SB}$

High-cost agent gets no rent

Second-best transfers are $\underline{t}^{SB}=\underline{\theta}\underline{q}^{SB}+(\bar{\theta}-\underline{\theta})\bar{q}^{SB}$ and $\bar{t}^{SB}=\bar{\theta}\bar{q}^{SB}$

Graphical Illustration

Shut-down policy: only low-cost agent produces

This is optimal if

$$\upsilon\left(S(\underline{q}^{*})-\underline{\theta}\underline{q}^{*}\right)\geq\underbrace{\upsilon\left(S(\underline{q}^{*})-\underline{\theta}\underline{q}^{*}\right)+(1-\upsilon)\left(S(\bar{q}^{SB})-\bar{\theta}\bar{q}^{SB}\right)}_{\text{Expected Social Surplus}}-\underbrace{\upsilon(\bar{\theta}-\underline{\theta})\bar{q}^{SB}}_{\text{Expected Information Rent}}\text{, or}$$

$$\underbrace{\upsilon(\bar{\theta}-\underline{\theta})\bar{q}^{SB}}_{\text{Expected Information Rent}}\geq\underbrace{(1-\upsilon)\left(S(\bar{q}^{SB})-\bar{\theta}\bar{q}^{SB}\right)}_{\text{Expected Incremental Social Surplus}}$$

Should the principle offer more options on the menu?

Should principle allow the agent to communicate by other means?

The answer is no and is known as the Revelation Principle

Recall that $A=\{(q,t):q\geq 0,-\infty<t<\infty\}$ is the set of feasible allocation: P and A can commit to transfer t and produce q

A **mechanism** is a message space M and a mapping $\tilde{g}:M\rightarrow A$ ($\{\tilde{q}(m),\tilde{t}(m)\}_{m\in M}$)

The agent chooses the optimal message (what if several messages are optimal?)

$$\tilde{t}(m^*(\theta))-\theta\tilde{q}(m^*(\theta))\geq \tilde{t}(m)-\theta\tilde{q}(m) \qquad \text{for all } m\in M$$

This induces an allocation rule: $a:\Theta\rightarrow A$ ($\{\tilde{q}(m^*(\theta)),\tilde{t}(m^*(\theta))\}_{\theta\in\Theta}$)

A **direct revelation mechanism** is a mapping $g:\Theta\rightarrow A$ ($\{q(\theta),t(\theta)\}_{\theta\in\Theta}$)

A **truthful direct revelation mechanism** is a mapping $g:\Theta\rightarrow A$ that is incentive compatible

$$t(\bar{\theta})-\bar{\theta}q(\bar{\theta})\geq t(\underline{\theta})-\bar{\theta}q(\underline{\theta})$$

$$t(\underline{\theta})-\underline{\theta}q(\underline{\theta})\geq t(\bar{\theta})-\underline{\theta}q(\bar{\theta})$$

The **Revelation Principle**: Any allocation rule induced by a mechanism $(M,\tilde{g})$ can be implemented with a truthful direct revelation mechanism.

Let $(q(\theta),t(\theta))=(\tilde{q}(m^*(\theta)),\tilde{t}(m^*(\theta)))$ for all $\theta\in\Theta$

By definition, $\{(q(\theta),t(\theta))\}$ is a direct mechanism

It is also truthful:

$$t(\bar{\theta})-\bar{\theta}q(\bar{\theta})=\tilde{t}(m^*(\bar{\theta}))-\bar{\theta}\tilde{q}(m^*(\bar{\theta}))\geq \tilde{t}(m^*(\underline{\theta}))-\bar{\theta}\tilde{q}(m^*(\underline{\theta}))=t(\underline{\theta})-\bar{\theta}q(\underline{\theta})$$

$$t(\underline{\theta})-\underline{\theta}q(\underline{\theta})=\tilde{t}(m^*(\underline{\theta}))-\underline{\theta}\tilde{q}(m^*(\underline{\theta}))\geq \tilde{t}(m^*(\bar{\theta}))-\underline{\theta}\tilde{q}(m^*(\bar{\theta}))=t(\bar{\theta})-\underline{\theta}q(\bar{\theta})$$

Applications

1. **Regulation of monopoly**: the regulator chooses the output and compensation for the firm

Monopoly's profit is $U = t - \theta q$

Consumer surplus is $S(q) - t$

The regulator is concerned with consumer welfare and his objective function is

$$S(q) - t + \alpha(t - \theta q) = S(q) - \theta q - (1-\alpha)(t - \theta q) = S(q) - \theta q - (1-\alpha)U$$

The regulator takes into account that the firm wants to overstate its cost

$$\max_{\underline{q},\bar{q}} \underbrace{\upsilon\left(S(\underline{q}) - \underline{\theta}\underline{q}\right) + (1-\upsilon)\left(S(\bar{q}) - \bar{\theta}\bar{q}\right)}_{\text{Expected Social Surplus}} - (1-\alpha) \underbrace{\upsilon(\bar{\theta} - \underline{\theta})\bar{q}}_{\text{Expected Information Rent}}$$

$$S'(\underline{q}^{SB}) = \underline{\theta}$$

$$S'(\bar{q}^{SB}) = \bar{\theta} + (1-\alpha)\frac{\upsilon}{1-\upsilon}(\bar{\theta} - \underline{\theta})$$

If the regulator values consumer and firm welfare equally, he will implement the first-best outputs

2. **Nonlinear pricing by a monopoly**

The firm's profit is $V = t - cq$

A buyer's utility function is $U = u(\theta q) - t$

Incentive and participation constraints become

$$\underline{U} = u(\underline{\theta}\underline{q}) - \underline{t} \geq \underline{\theta}u(\bar{q}) - \bar{t} = u(\bar{\theta}\bar{q}) - \bar{t} + u(\underline{\theta}\bar{q}) - u(\bar{\theta}\bar{q}) = \bar{U} - (u(\bar{\theta}\bar{q}) - u(\underline{\theta}\bar{q}))$$

$$\bar{U} = u(\bar{\theta}\bar{q}) - \bar{t} \geq u(\bar{\theta}\underline{q}) - \underline{t} = u(\underline{\theta}\underline{q}) - \bar{t} + u(\bar{\theta}\underline{q}) - u(\underline{\theta}\underline{q}) = \underline{U} + u(\bar{\theta}\underline{q}) - u(\underline{\theta}\underline{q})$$

$$\underline{U} = u(\underline{\theta}\underline{q}) - \underline{t} \geq 0$$

$$\bar{U} = u(\bar{\theta}\bar{q}) - \bar{t} \geq 0$$

The firm's profit becomes

$$\max_{\underline{q},\bar{q},\underline{U},\bar{U}} \underbrace{\upsilon\left(u(\underline{\theta}\underline{q}) - c\underline{q}\right) + (1-\upsilon)\left(u(\bar{\theta}\bar{q}) - c\bar{q}\right)}_{\text{Expected Social Surplus}} - \underbrace{\left(\upsilon\underline{U} + (1-\upsilon)\bar{U}\right)}_{\text{Expected Information Rent}}$$ subject to ICs and PCs

Only high-WTP buyers want to deviate and buy low quantity:

$$\max_{\underline{q},\bar{q}} \underbrace{\upsilon\left(u(\underline{\theta}\underline{q})-c\underline{q}\right)+(1-\upsilon)\left(u(\bar{\theta}\bar{q})-c\bar{q}\right)}_{\text{Expected Social Surplus}}-\underbrace{(1-\upsilon)(u(\bar{\theta}\,\underline{q})-u(\underline{\theta}\underline{q}))}_{\text{Expected Information Rent}}$$

Maximization yields

$$\bar{\theta}u'(\bar{\theta}\bar{q}^{SB})=c$$

$$\underline{\theta}u'(\underline{\theta}\underline{q}^{SB})-\frac{1-\upsilon}{\upsilon}(\bar{\theta}u'(\bar{\theta}\,\underline{q}^{SB})-\underline{\theta}u'(\underline{\theta}\underline{q}^{SB}))=c$$

The unit prices for high and low quantity are

$$\frac{\underline{t}^{SB}}{\underline{q}^{SB}}=\frac{u(\underline{\theta}\underline{q}^{SB})-\underline{U}^{SB}}{\underline{q}^{SB}}=\frac{u(\underline{\theta}\underline{q}^{SB})}{\underline{q}^{SB}}$$

$$\frac{\bar{t}^{SB}}{\bar{q}^{SB}}=\frac{u(\bar{\theta}\bar{q}^{SB})-\bar{U}^{SB}}{\bar{q}^{SB}}=\frac{u(\bar{\theta}\bar{q}^{SB})-u(\bar{\theta}\,\underline{q}^{SB})+u(\underline{\theta}\underline{q}^{SB})}{\bar{q}^{SB}}$$

$$\frac{u(\bar{\theta}\bar{q}^{SB})-u(\bar{\theta}\,\underline{q}^{SB})+u(\underline{\theta}\underline{q}^{SB})}{\bar{q}^{SB}}<\frac{u(\underline{\theta}\underline{q}^{SB})}{\underline{q}^{SB}}\text{, or }\frac{u(\bar{\theta}\bar{q}^{SB})-u(\bar{\theta}\,\underline{q}^{SB})}{\bar{q}^{SB}-\underline{q}^{SB}}<\frac{u(\underline{\theta}\underline{q}^{SB})}{\underline{q}^{SB}}$$

a quantity discount

3. **Quality and price discrimination**

The firm's profit is $V=t-C(q)$

The agent's utility is $U=\theta q-t$

Incentive and participation constraints become

$$\underline{U}=\underline{\theta}\underline{q}-\underline{t}\geq\underline{\theta}u(\bar{q})-\bar{t}=\bar{\theta}\bar{q}-\bar{t}+\underline{\theta}\bar{q}-\bar{\theta}\bar{q}=\bar{U}-(\bar{\theta}-\underline{\theta})\bar{q}$$

$$\bar{U}=\bar{\theta}\bar{q}-\bar{t}\geq\bar{\theta}\,\underline{q}-\underline{t}=\underline{\theta}\underline{q}-\bar{t}+\bar{\theta}\,\underline{q}-\underline{\theta}\underline{q}=\underline{U}+(\bar{\theta}-\underline{\theta})\underline{q}$$

$$\underline{U}=\underline{\theta}\underline{q}-\underline{t}\geq 0$$

$$\bar{U}=\bar{\theta}\bar{q}-\bar{t}\geq 0$$

The firm's profit becomes

$$\max_{\underline{q},\bar{q},\underline{U},\bar{U}} \underbrace{\upsilon\left(\underline{\theta}\underline{q}-C(\underline{q})\right)+(1-\upsilon)\left(\bar{\theta}\bar{q}-C(\bar{q})\right)}_{\text{Expected Social Surplus}}-\underbrace{\left(\upsilon\underline{U}+(1-\upsilon)\bar{U}\right)}_{\text{Expected Information Rent}}$$ subject to ICs and PCs

Only high-WTP buyers want to deviate and buy low quality:

$$\max_{\underline{q},\bar{q}} \underbrace{\upsilon\left(\underline{\theta}\underline{q} - C(\underline{q})\right) + (1-\upsilon)\left(\bar{\theta}\bar{q} - C(\bar{q})\right)}_{\text{Expected Social Surplus}} - \underbrace{(1-\upsilon)(\bar{\theta}-\underline{\theta})\underline{q}}_{\text{Expected Information Rent}}$$

Maximization yields

$$\bar{\theta} = C'(\bar{q}^{SB})$$

$$\underline{\theta} - \frac{1-\upsilon}{\upsilon}(\bar{\theta}-\underline{\theta}) = C'(\underline{q}^{SB})$$

The low-quality product offered by the firm is of lower quality than the efficient low-quality product

4. **Loan contracts**

The lender (principal) offers a loan of size q at cost of Rq, R is a risk-free interest rate, and earns: $t - Rq$

The borrower (agent) invests and earns: $\theta f(q) - t$, where $f' > 0,\ f'' < 0$

Incentive and participation constraints become

$$\underline{U} = \underline{\theta} f(\underline{q}) - \underline{t} \geq \underline{\theta} f(\bar{q}) - \bar{t} = \bar{\theta} f(\bar{q}) - \bar{t} + \underline{\theta} f(\bar{q}) - \bar{\theta} f(\bar{q}) = \bar{U} - (\bar{\theta} - \underline{\theta}) f(\bar{q})$$

$$\bar{U} = \bar{\theta} f(\bar{q}) - \bar{t} \geq \bar{\theta} f(\underline{q}) - \underline{t} = \underline{\theta} f(\underline{q}) - \bar{t} + \bar{\theta} f(\underline{q}) - \underline{\theta}\underline{q} = \underline{U} + (\bar{\theta} - \underline{\theta}) f(\underline{q})$$

$$\underline{U} = \underline{\theta} f(\underline{q}) - \underline{t} \geq 0$$

$$\bar{U} = \bar{\theta} f(\bar{q}) - \bar{t} \geq 0$$

High-productivity borrower wants to deviate and get a smaller loan

$$\bar{\theta} f'(\bar{q}^{SB}) = R$$

$$[\underline{\theta} - \frac{1-\upsilon}{\upsilon}(\bar{\theta}-\underline{\theta})] f'(\underline{q}^{SB}) = R$$

Screening borrowers according to the size of their loans (less productive get smaller loans)

II. Moral Hazard

Agent (A) can exert effort $e \in \{0,1\}$ at cost $\psi(e)$, where $\psi(0) = 0 < \psi(1) = \psi$

A's utility is $U = u(t) - \psi(e)$, where $u' > 0, u'' < 0, u(0) = 0$ (we will need $h = u^{-1}$)

Output is stochastic: $\tilde{q} \in \{\underline{q}, \bar{q}\}$, $\underline{q} < \bar{q}$

$\Pr(\tilde{q} = \bar{q} \mid e = 1) = \pi_1$ $\Pr(\tilde{q} = \bar{q} \mid e = 0) = \pi_0$, $\pi_0 < \pi_1$ (FOSD property)

Principal (P)'s utility is $S(q) - t$, $S' > 0, S'' < 0$

$\pi_1 S(\bar{q}) + (1-\pi_1) S(\underline{q}) > \pi_0 S(\bar{q}) + (1-\pi_0) S(\underline{q})$ because $(\pi_1 - \pi_0)[S(\bar{q}) - S(\underline{q})] > 0$

Contracts

Same as before: Only variables q and t are observable and *verifiable*

P offers to A a contract $\{(\underline{q}, \underline{t}), (\bar{q}, \bar{t})\}$

Timing of events

1. P offers A a contract $\{(\underline{q}, \underline{t}), (\bar{q}, \bar{t})\}$
2. A accepts or refuses the contract
3. A exerts an effort ($e = 1$) or not ($e = 0$)
4. The output $\tilde{q}$ is realized
5. The contract is executed

Incentive feasible contracts

P gets

$\pi_1[S(\bar{q}) - \bar{t}] + (1-\pi_1)[S(\underline{q}) - \underline{t}]$ If A chooses $e = 1$

$\pi_0[S(\bar{q}) - \bar{t}] + (1-\pi_0)[S(\underline{q}) - \underline{t}]$ If A chooses $e = 0$

Incentive compatibility constraint (under moral hazard)

$\pi_1 u(\bar{t}) + (1-\pi_1) u(\underline{t}) - \psi \geq \pi_0 u(\bar{t}) + (1-\pi_0) u(\underline{t})$

Participation constraint

$\pi_1 u(\bar{t}) + (1-\pi_1) u(\underline{t}) - \psi \geq 0$

Benchmark: complete information about effort

If effort is verifiable, P offers a contract with transfers contingent on $\tilde{q}$ and e

If P offers $\{(\underline{q},\underline{t},e=1),(\bar{q},\bar{t},e=1),(\underline{q},\underline{t}=0,e=0),(\bar{q},\bar{t}=0,e=0)\}$, P's problem becomes

$\max_{\underline{t},\bar{t}} \pi_1[\bar{S}-\bar{t}]+(1-\pi_1)[\underline{S}-\underline{t}]$ subject to $\pi_1 u(\bar{t})+(1-\pi_1)u(\underline{t})-\psi \geq 0$

The first-order condition is

$$-\pi_1+\mu\pi_1 u'(\bar{t}^*)=0$$

$$-(1-\pi_1)+\mu(1-\pi_1)u'(\underline{t}^*)=0$$

$u'(\bar{t}^*)=u'(\underline{t}^*)=\frac{1}{\mu}$ => $\bar{t}^*=\underline{t}^*=t^*$, where $\pi_1 u(\bar{t}^*)+(1-\pi_1)u(\underline{t}^*)-\psi=u(t^*)-\psi=0$, $t^*=h(\psi)$

full insurance, $C^{FB}\equiv t^*=h(\psi)$

P gets

$\pi_1[S(\bar{q})-\bar{t}^*]+(1-\pi_1)[S(\underline{q})-\underline{t}^*]=\pi_1 S(\bar{q})+(1-\pi_1)S(\underline{q})-h(\psi)$ If A chooses $e=1$

$\pi_0[S(\bar{q})-\bar{t}]+(1-\pi_0)[S(\underline{q})-\underline{t}]=\pi_0 S(\bar{q})+(1-\pi_0)S(\underline{q})$ If A chooses $e=0$

Inducing effort is optimal if

$\pi_1 S(\bar{q})+(1-\pi_1)S(\underline{q})-h(\psi)\geq \pi_0 S(\bar{q})+(1-\pi_0)S(\underline{q})$, or

$$\underbrace{(\pi_1-\pi_0)[S(\bar{q})-S(\underline{q})]}_{\text{Expected gain from effort}} \geq \underbrace{h(\psi)}_{\text{First-best cost of inducing effort}}$$

Risk-neutral agent

$$u(t)=t, h(u)=u$$

P's problem becomes

$\max_{\underline{t},\bar{t}} \pi_1[\bar{S}-\bar{t}]+(1-\pi_1)[\underline{S}-\underline{t}]$ subject to

$$\pi_1\bar{t}+(1-\pi_1)\underline{t}-\psi \geq \pi_0\bar{t}+(1-\pi_0)\underline{t}$$

$$\pi_1\bar{t}+(1-\pi_1)\underline{t}-\psi \geq 0$$

If both constrains bind, we have

$$\bar{t} = -\frac{1-\pi_0}{\pi_0}\underline{t}, \ \pi_1(-\frac{1-\pi_0}{\pi_0})\underline{t} + (1-\pi_1)\underline{t} - \psi = 0,$$

$$\underline{t}^* = -\frac{\pi_0}{\pi_1-\pi_0}\psi \text{ and } \bar{t}^* = \frac{1-\pi_0}{\pi_1-\pi_0}\psi$$

Big rewards and big punishments:

If $q = \bar{q}$, A gets $\bar{U}^* = \bar{t}^* - \psi = \frac{1-\pi_0}{\pi_1-\pi_0}\psi - \psi = \frac{1-\pi_1}{\pi_1-\pi_0}\psi > 0$

If $q = \underline{q}$, A gets $\underline{U}^* = \underline{t}^* - \psi = -\frac{\pi_0}{\pi_1-\pi_0}\psi - \psi = -\frac{\pi_1}{\pi_1-\pi_0}\psi < 0$

The expected payment is $\pi_1\bar{t}^* + (1-\pi_1)\underline{t}^* = \pi_1\frac{1-\pi_0}{\pi_1-\pi_0}\psi + (1-\pi_1)[-\frac{\pi_0}{\pi_1-\pi_0}\psi] = \psi$

=> P implements the first-best level of effort at no additional cost

At optimum only the participation constraint needs to bind

P can also make A the **residual claimant**: $(\underline{t}^*, \bar{t}^*) = (S(\underline{q}) - T^*, S(\bar{q}) - T^*)$

IC constraint is satisfied (with a slack):

$$\pi_1[S(\bar{q}) - T^*] + (1-\pi_1)[S(\underline{q}) - T^*] - \psi \geq \pi_0[S(\bar{q}) - T^*] + (1-\pi_0)[S(\underline{q}) - T^*], \text{ or}$$

$$\pi_1 S(\bar{q}) + (1-\pi_1)S(\underline{q}) - \psi \geq \pi_0 S(\bar{q}) + (1-\pi_0)S(\underline{q}), \text{ or } \underbrace{(\pi_1-\pi_0)[S(\bar{q}) - S(\underline{q})]}_{\text{Expected gain from effort}} \geq \underbrace{\psi}_{\text{First-best cost of inducing effort}}$$

The upfront payment T^* solves: $\pi_1[S(\bar{q}) - T^*] + (1-\pi_1)[S(\underline{q}) - T^*] - \psi = 0$

$T^* = \pi_1 S(\bar{q}) + (1-\pi_1)S(\underline{q}) - \psi$ (what does this tell us about the role of property rights?)

Two types of transaction costs: **limited liability** and **risk aversion**

Limited Liability Rent

A is risk-neutral but transfers are constrained (limited wealth)

$\bar{t} \geq -l$ and $\underline{t} \geq -l$ for some $l \geq 0$

P's problem now becomes

$\max_{\underline{t},\bar{t}} \pi_1[\bar{S} - \bar{t}] + (1-\pi_1)[\underline{S} - \underline{t}]$ subject to

$$\pi_1\bar{t} + (1-\pi_1)\underline{t} - \psi \geq \pi_0\bar{t} + (1-\pi_0)\underline{t}$$

$$\pi_1\bar{t} + (1-\pi_1)\underline{t} - \psi \geq 0$$

$$\bar{t} \geq -l$$

$$\underline{t} \geq -l$$

If $\underline{t}^{LL} = \underline{t}^* = -\dfrac{\pi_0}{\pi_1 - \pi_0}\psi \geq -l$ and $\bar{t}^{LL} = \bar{t}^* = \dfrac{1-\pi_0}{\pi_1 - \pi_0}\psi \geq -l$, or $l \geq \dfrac{\pi_0}{\pi_1 - \pi_0}\psi$

=> no efficiency loss and the agent gets no limited liability rent.

If $l < \dfrac{\pi_0}{\pi_1 - \pi_0}\psi$, $\underline{t}^{LL} = -l$, and IC constraint binds:

$$\pi_1\bar{t} + (1-\pi_1)(-l) - \psi = \pi_0\bar{t} + (1-\pi_0)(-l), \text{ or}$$

$$\bar{t}^{LL} = -l + \frac{\psi}{\pi_1 - \pi_0}.$$

A now gets expected limited liability rent:

$$\pi_1\bar{t}^{LL} + (1-\pi_1)\underline{t}^{LL} - \psi = -l + \frac{\pi_1\psi}{\pi_1 - \pi_0} - \psi = -l + \frac{\pi_0\psi}{\pi_1 - \pi_0} > 0$$

The expected transfer is now

$$\pi_1\bar{t}^{LL} + (1-\pi_1)\underline{t}^{LL} = -l + \frac{\pi_1\psi}{\pi_1 - \pi_0} > \psi$$

P implements high level of effort if

$$\underbrace{(\pi_1 - \pi_0)[S(\bar{q}) - S(\underline{q})]}_{\substack{\text{Expected}\\ \text{gain}\\ \text{from effort}}} \geq \underbrace{\pi_1\bar{t}^{LL} + (1-\pi_1)\underline{t}^{LL}}_{\substack{\text{Second-best cost}\\ \text{of inducing}\\ \text{effort}}} = \underbrace{\psi - l + \frac{\pi_0\psi}{\pi_1 - \pi_0}}_{\substack{\text{Second-best cost}\\ \text{of inducing}\\ \text{effort}}} > \underbrace{\psi}_{\substack{\text{First-best cost}\\ \text{of inducing}\\ \text{effort}}}$$

Under-provision of effort for $\underbrace{\psi}_{\substack{\text{First-best cost}\\ \text{of inducing}\\ \text{effort}}} < \underbrace{(\pi_1 - \pi_0)[S(\bar{q}) - S(\underline{q})]}_{\substack{\text{Expected}\\ \text{gain}\\ \text{from effort}}} < \underbrace{\psi - l + \frac{\pi_0 \psi}{\pi_1 - \pi_0}}_{\substack{\text{Second-best cost}\\ \text{of inducing}\\ \text{effort}}}$

Risk-averse agent

P's problem now becomes

$\max_{\underline{t},\bar{t}} \pi_1[\bar{S} - \bar{t}] + (1-\pi_1)[\underline{S} - \underline{t}]$ subject to

$$\pi_1 u(\bar{t}) + (1-\pi_1)u(\underline{t}) - \psi \geq \pi_0 u(\bar{t}) + (1-\pi_0)u(\underline{t})$$

$$\pi_1 u(\bar{t}) + (1-\pi_1)u(\underline{t}) - \psi \geq 0$$

Let $\bar{t} = h(\bar{u}), \underline{t} = h(\underline{u})$, where $\bar{u} = u(\bar{t}), \underline{u} = u(\underline{t})$:

$\max_{\underline{u},\bar{u}} \pi_1[\bar{S} - h(\bar{u})] + (1-\pi_1)[\underline{S} - h(\underline{u})]$ subject to

$$\pi_1 \bar{u} + (1-\pi_1)\underline{u} - \psi \geq \pi_0 \bar{u} + (1-\pi_0)\underline{u}$$

$$\pi_1 \bar{u} + (1-\pi_1)\underline{u} - \psi \geq 0$$

The first-order conditions are

$$-\pi_1 h'(\bar{u}) + \lambda(\pi_1 - \pi_0) + \mu\pi_1 = 0$$

$$-(1-\pi_1)h'(\underline{u}) - \lambda(\pi_1 - \pi_0) + \mu(1-\pi_1) = 0$$

(Count the number of variables and optimality equations?)

Rearranging we get

$$h'(\bar{u}) = \frac{\pi_1 - \pi_0}{\pi_1}\lambda + \mu$$

$$h'(\underline{u}) = -\frac{\pi_1 - \pi_0}{1-\pi_1}\lambda + \mu$$

Check that

$$h'(\bar{u})\frac{1}{1-\pi_1} = \frac{\pi_1-\pi_0}{\pi_1(1-\pi_1)}\lambda + \frac{1}{1-\pi_1}\mu$$

$$h'(\underline{u})\frac{1}{\pi_1} = -\frac{\pi_1-\pi_0}{\pi_1(1-\pi_1)}\lambda + \frac{1}{\pi_1}\mu \Rightarrow \quad \mu = \pi_1 h'(\bar{u}) + (1-\pi_1)h'(\underline{u}) > 0$$

Check that

$$\lambda = \frac{1-\pi_1}{\pi_1-\pi_0}(\mu - h'(\underline{u})) = \frac{(1-\pi_1)\pi_1}{\pi_1-\pi_0}(h'(\bar{u}) - h'(\underline{u})) > 0$$

From the IC constraint we have

$$\pi_1\bar{u} + (1-\pi_1)\underline{u} - \psi \geq \pi_0\bar{u} + (1-\pi_0)\underline{u}\text{, or } (\pi_1-\pi_0)(\bar{u}-\underline{u}) \geq \psi\text{, or } \bar{u}-\underline{u} \geq \frac{\psi}{\pi_1-\pi_0} > 0$$

If u is concave, then h is convex, so that both multipliers are strictly positive.

Both IC and PC must bind at optimum.

Solving this system of equations yields

$$\pi_1\bar{u}^{SB} + (1-\pi_1)\underline{u}^{SB} - \psi = \pi_0\bar{u}^{SB} + (1-\pi_0)\underline{u}^{SB}$$

$$\pi_1\bar{u}^{SB} + (1-\pi_1)\underline{u}^{SB} - \psi = 0$$

$u(\underline{t}^{SB}) = -\frac{\pi_0}{\pi_1-\pi_0}\psi$ and $u(\bar{t}^{SB}) = \frac{1-\pi_0}{\pi_1-\pi_0}\psi$ (recall the solution under risk-neutrality)

The transfers are

$$\underline{t}^{SB} = h(-\frac{\pi_0}{\pi_1-\pi_0}\psi) < h(\psi) < h(\frac{1-\pi_0}{\pi_1-\pi_0}\psi) = \bar{t}^{SB}$$

No full insurance: agent bears some risk.

Because agent is risk-averse and transfers are random, he accepts the gamble only if the expected payment exceeds the cost of effort:

$$C^{SB} \equiv (1-\pi_1)\underline{t}^{SB} + \pi_1\bar{t}^{SB} = (1-\pi_1)h(-\frac{\pi_0}{\pi_1-\pi_0}\psi) + \pi_1 h(\frac{1-\pi_0}{\pi_1-\pi_0}\psi)$$

$$> h(-(1-\pi_1)\frac{\pi_0}{\pi_1-\pi_0}\psi + \pi_1\frac{1-\pi_0}{\pi_1-\pi_0}\psi) = h(\psi) = C^{FB}$$

Under-provision of effort if

$$\underbrace{\psi}_{\substack{\text{First-best cost}\\ \text{of inducing}\\ \text{effort}}} < \underbrace{(\pi_1-\pi_0)[S(\bar{q})-S(\underline{q})]}_{\substack{\text{Expected}\\ \text{gain}\\ \text{from effort}}} < \underbrace{(1-\pi_1)h(-\frac{\pi_0}{\pi_1-\pi_0}\psi)+\pi_1 h(\frac{1-\pi_0}{\pi_1-\pi_0}\psi)}_{\substack{\text{Second-best cost}\\ \text{of inducing}\\ \text{effort}}}$$

Consider the following utility function of the agent:

$u(t)=\dfrac{-1+\sqrt{1+2rt}}{r}, t>-\dfrac{1}{2r},\ r>0,\ -\dfrac{u''(0)}{u'(0)}=r$ is the degree of absolute risk aversion

$$h(u)=u+\frac{r}{2}u^2$$

The second-best cost of implementing high effort becomes

$$C^{SB}=(1-\pi_1)h(-\frac{\pi_0}{\pi_1-\pi_0}\psi)+\pi_1 h(\frac{1-\pi_0}{\pi_1-\pi_0}\psi)$$

$$=-(1-\pi_1)\frac{\pi_0}{\pi_1-\pi_0}\psi+\pi_1\frac{1-\pi_0}{\pi_1-\pi_0}\psi+\frac{r}{2}[(1-\pi_1)\left(\frac{\pi_0}{\pi_1-\pi_0}\psi\right)^2+\pi_1\left(\frac{1-\pi_0}{\pi_1-\pi_0}\psi\right)^2]$$

$$=\psi+\frac{r}{2}\left(\frac{\psi}{\pi_1-\pi_0}\right)^2[(1-\pi_1)(\pi_0)^2+\pi_1(1-\pi_0)^2]=\psi+\frac{r}{2}\left(\frac{\psi}{\pi_1-\pi_0}\right)^2[\pi_1(1-\pi_0)-\pi_0(\pi_1-\pi_0)]$$

$$=\psi+\frac{r}{2}(\psi)^2+\frac{r}{2}\left(\frac{\psi}{\pi_1-\pi_0}\right)^2\pi_1(1-\pi_1)$$

$$C^{FB}=h(\psi)=\psi+\frac{r}{2}(\psi)^2$$

$C^{SB}-C^{FB}=\dfrac{r}{2}\left(\dfrac{\psi}{\pi_1-\pi_0}\right)^2\pi_1(1-\pi_1)$ is the informational cost of the agency under risk-aversion

Applications

1. Labor market (the wage of efficiency)

A risk-neutral agent works for a firm and by exerting effort $e \in \{0,1\}$ can create the firm's added value $\bar{S}$ (resp. $\underline{S}$ with probability $\pi(e)$ (resp. $1-\pi(e)$). The agent can be rewarded for a good performance but cannot be punished for a bad outcome ($l = 0$). The firm solves

$$\max_{\underline{t},\bar{t}} \pi_1[\bar{S}-\bar{t}]+(1-\pi_1)[\underline{S}-\underline{t}] \text{ subject to}$$

$$\pi_1\bar{t}+(1-\pi_1)\underline{t}-\psi \geq \pi_0\bar{t}+(1-\pi_0)\underline{t}$$

$$\pi_1\bar{t}+(1-\pi_1)\underline{t}-\psi \geq 0$$

$$\bar{t} \geq -l$$

$$\underline{t} \geq -l$$

The optimal solution is

$\underline{t}^* = 0$, $\bar{t}^* = \dfrac{\psi}{\pi_1-\pi_0}$ is called an efficiency wage

The firm may underprovide effort if the incentive cost is too high

The principal gives up a positive share of the firm's profit to the agent

The firm gets $\pi_1\bar{S}+(1-\pi_1)\underline{S}-\dfrac{\pi_1\psi}{\pi_1-\pi_0}$

The agent gets $\dfrac{\pi_1\psi}{\pi_1-\pi_0}-\psi = \dfrac{\pi_0\psi}{\pi_1-\pi_0}$

2. Sharecropping

The principal is a landlord and the agent is the tenant

The agent probabilistically controls the quantity of agricultural output

The solution is the same as before

In reality, the contractual arrangement take a linear sharing rule:

the landlord gives the tenant a fixed share α of the output value

The landlord's problem becomes

$$\max_{\alpha}(1-\alpha)(\pi_1\bar{q}+(1-\pi_1)\underline{q}) \text{ subject to}$$

$$\alpha(\pi_1\bar{q}+(1-\pi_1)\underline{q})-\psi \geq \alpha(\pi_0\bar{q}+(1-\pi_0)\underline{q})$$

$$\alpha(\pi_1\bar{q}+(1-\pi_1)\underline{q})-\psi \geq 0$$

Only the IC constraint binds (why?)

$\alpha^{SB}=\dfrac{\psi}{(\pi_1-\pi_0)(\bar{q}-\underline{q})}<1$ if high effort is efficient

Under the sharing rule the landlord gets

$$(1-\frac{\psi}{(\pi_1-\pi_0)(\bar{q}-\underline{q})})(\pi_1\bar{q}+(1-\pi_1)\underline{q})=\pi_1\bar{q}+(1-\pi_1)\underline{q}-\frac{\psi}{(\pi_1-\pi_0)(\bar{q}-\underline{q})}(\pi_1\bar{q}+(1-\pi_1)\underline{q})$$

The tenant gets

$$\frac{\psi}{(\pi_1-\pi_0)(\bar{q}-\underline{q})}(\pi_1\bar{q}+(1-\pi_1)\underline{q})-\psi=\frac{\pi_0\psi}{\pi_1-\pi_0}+\underline{q}\frac{\psi}{(\pi_1-\pi_0)(\bar{q}-\underline{q})}>\frac{\pi_0\psi}{\pi_1-\pi_0}$$

A fixed fee can extract the agent's information rent due to the sharing rule

3. Wholesale contracts

Consider a manufacturer-retailer relationship

The manufacturer supplies at constant marginal cost c an intermediate good to the risk-averse retailer

Demand depends on the manufacturer's effort $e\in\{0,1\}$

$\bar{D}(p)$ (resp. $\underline{D}(p)$) with probability $\pi(e)$ (resp. $1-\pi(e)$), where p is the price

The effort is exerted by the retailer such as advertising or after-sales services

The manufacturer offers the wholesale contract that consists of a retail price maintenance agreement

$\{(\underline{t},\underline{p}),(\bar{t},\bar{p})\}$ to induce effort

The manufacturer solves

$\max_{\{(\underline{t},\underline{p}),(\bar{t},\bar{p})\}} \pi_1(\underline{p}-c)\underline{D}(\underline{p})-\underline{t})+(1-\pi_1)(\bar{p}-c)\bar{D}(\bar{p})-\bar{t})$ subject to

$$\pi_1 u(\bar{t})+(1-\pi_1)u(\underline{t})-\psi \geq \pi_0 u(\bar{t})+(1-\pi_0)u(\underline{t})$$

$$\pi_1 u(\bar{t})+(1-\pi_1)u(\underline{t})-\psi \geq 0$$

The pricing rule does not depend on the incentive problem: $p+\dfrac{D(p)}{D'(p)}=c$

4. Financial contracts

A risk-averse entrepreneur wants to start a project that requires an initial investment of size I

The financial contract consists of repayments contingent on the project's success or failure: $\{\underline{t}, \bar{t}\}$

$$\max_{\{\underline{t},,\bar{t}\}} \pi_1 \bar{t} + (1-\pi_1)\underline{t} - I$$

subject to

$$\pi_1 u(\bar{S} - \bar{t}) + (1-\pi_1) u(\underline{S} - \underline{t}) - \psi \geq \pi_0 u(\bar{S} - \bar{t}) + (1-\pi_0) u(\underline{S} - \underline{t})$$

$$\pi_1 u(\bar{S} - \bar{t}) + (1-\pi_1) u(\underline{S} - \underline{t}) - \psi \geq 0$$

Let $\bar{z} = \bar{S} - \bar{t}, \underline{z} = \underline{S} - \underline{t}$

$$\max_{\{\underline{z},\bar{z}\}} \pi_1(\bar{S} - \bar{z}) + (1-\pi_1)(\underline{S} - \underline{z})$$

subject to

$$\pi_1 u(\bar{z}) + (1-\pi_1) u(\underline{z}) - \psi \geq \pi_0 u(\bar{z}) + (1-\pi_0) u(\underline{z})$$

$$\pi_1 u(\bar{z}) + (1-\pi_1) u(\underline{z}) - \psi \geq 0$$

The lender's expected profit is

$$\pi_1 \bar{S} + (1-\pi_1)\underline{S} - I - C^{SB} = \pi_1 \bar{S} + (1-\pi_1)\underline{S} - I - (1-\pi_1) h(-\frac{\pi_0}{\pi_1 - \pi_0}\psi) - \pi_1 h(\frac{1-\pi_0}{\pi_1 - \pi_0}\psi)$$

So the project is financed if

$$I \leq \pi_1 \bar{S} + (1-\pi_1)\underline{S} - I - C^{SB}$$

Under complete information the project is financed if

$$I \leq \pi_1 \bar{S} + (1-\pi_1)\underline{S} - I - C^{FB} = \pi_1 \bar{S} + (1-\pi_1)\underline{S} - I - h(\psi)$$

Under limited liability, $\bar{z}, \underline{z} \geq 0$, the optimal payments are given by

$\underline{z}^{LL} = 0$, and $\pi_1 u(\bar{z}^{LL}) - \psi = \pi_0 u(\bar{z}^{LL})$, or $\bar{z}^{LL} = h(\frac{\psi}{\pi_1 - \pi_0})$.

This is similar to a debt contract where the lender gets the asset in the case of default (project failure)

$$\bar{z}^{LL} - \underline{z}^{LL} = h(\frac{\psi}{\pi_1 - \pi_0}) > h(\frac{1-\pi_0}{\pi_1 - \pi_0}\psi) - h(-\frac{\pi_0}{\pi_1 - \pi_0}\psi) = \bar{z}^{SB} - \underline{z}^{SB}$$

because h is convex and $\frac{\psi}{\pi_1 - \pi_0} - 0 = \frac{1-\pi_0}{\pi_1 - \pi_0}\psi - \frac{\pi_0}{\pi_1 - \pi_0}\psi$

=> debt contract has less power

4.1. Choice of project with private benefits from some projects

Risk-neutral manager with limited liability chooses between good project (high probability of return $\bar{S}$ and no private benefit) and a bad project (low probability of return $\bar{S}$ and private benefit $B > 0$). The problem of shareholders becomes

$$\max_{\{\underline{z},\bar{z}\}} \pi_1(\bar{S} - \bar{z}) + (1-\pi_1)(\underline{S} - \underline{z})$$

subject to

$$\pi_1\bar{z} + (1-\pi_1)\underline{z} \geq \pi_0\bar{z} + (1-\pi_0)\underline{z} + B$$

$$\pi_1\bar{z} + (1-\pi_1)\underline{z} \geq 0$$

$$\bar{z}, \underline{z} \geq 0$$

The optimal contract is $(\underline{z}^{LL}, \bar{z}^{LL}) = (0, \frac{B}{\pi_1 - \pi_0})$

5. Insurance contracts

Risk-averse agent with initial wealth w can exert effort to reduce the probability of an accident that results in the damage worth d from π_0 to π_1. The risk-neutral insurance company solves

$$\max_{\{\underline{t},,\bar{t}\}} \pi_1\bar{t} + (1-\pi_1)\underline{t}$$

subject to

$$\pi_1 u(w-\bar{t}) + (1-\pi_1)u(w-d-\underline{t}) - \psi \geq \pi_0 u(w-\bar{t}) + (1-\pi_0)u(w-d-\underline{t})$$

$$\pi_1 u(w-\bar{t}) + (1-\pi_1)u(w-d-\underline{t}) - \psi \geq u(\hat{w})$$

$u(\hat{w}) = \max[\ \pi_1 u(w) + (1-\pi_1)u(w-d) - \psi, \pi_0 u(w) + (1-\pi_0)u(w-d)]$ is certainty equivalent if uninsured

Both IC and PC constraints bind

$$\pi_1\bar{u} + (1-\pi_1)\underline{u} - \psi = \pi_0\bar{u} + (1-\pi_0)\underline{u}$$

$$\pi_1\bar{u} + (1-\pi_1)\underline{u} - \psi = u(\hat{w})$$

Solving this system of equations yields

$$\bar{u} = \frac{\psi}{\pi_1 - \pi_0} + \underline{u}$$

$$\underline{u} = -\pi_1 \frac{\psi}{\pi_1 - \pi_0} + \psi + u(\hat{w}) \text{, or } \bar{t} = w - h(-\pi_1 \frac{\psi}{\pi_1 - \pi_0} + \psi + u(\hat{w}))$$

$$\bar{u} = \frac{\psi}{\pi_1 - \pi_0} + \underline{u} = (1-\pi_1)\frac{\psi}{\pi_1 - \pi_0} + \psi + u(\hat{w}) \text{, or } \bar{t} = w - d - h((1-\pi_1)\frac{\psi}{\pi_1 - \pi_0} + \psi + u(\hat{w}))$$

The second-best cost of inducing effort is given by

$$C^{SB} = (1-\pi_1)h(-\pi_1 \frac{\psi}{\pi_1 - \pi_0} + \psi + u(\hat{w})) + \pi_1 h((1-\pi_1)\frac{\psi}{\pi_1 - \pi_0} + \psi + u(\hat{w}))$$

Under complete information about effort, the cost of inducing effort is given by

$$C^{FB} = h(\psi + u(\hat{w}))$$

The agency cost

$AC = C^{SB} - C^{FB}$ is increasing in the initial wealth if h' is convex

= > More distortion in the decision to induce effort by insurance companies when the agent is wealthier

III. Nonverifiability: Relational Contracting

Suppose that the agent's output is nonverifiable: weak institutions and enforcement of contracts in developing countries.

Why is this a problem for contracting between the principal and the agent?

Both still observe output and interact over time

Let δ denote the discount factor

Stationary contracts are optimal (Levin 2003)

Consider a compensation package that consists of a fixed base wage W and a promised bonus b for high output.

The agent is willing to put in effort if

$$\pi_1 b + W - \psi \geq \pi_0 b + W \text{, or } b \geq \frac{\psi}{\pi_1 - \pi_0}$$

The principal is willing to offer the promised payment when output is high if

$$\underbrace{\overline{q}-b-W}_{\substack{\text{Current Profit}\\ \text{withoutReneging}}} + \underbrace{\delta\frac{\pi_1\overline{q}+(1-\pi_1)\underline{q}-\pi_1 b-W}{1-\delta}}_{\substack{\text{Discounted Exepected Future Profits}\\ \text{withoutReneging}}} \geq \underbrace{\overline{q}-W}_{\substack{\text{Current Profit}\\ \text{from Reneging}}} + \underbrace{\delta\frac{\pi_0\overline{q}+(1-\pi_0)\underline{q}}{1-\delta}}_{\substack{\text{DiscountedExepected FutureProfits}\\ \text{after Reneging}}}$$

The principal can set the base wage to extract the entire information rent of the agent:

$$\pi_1 b + W - \psi = 0.$$

A relational contract induces effort if and only if

$$-b+\delta\frac{\pi_1\overline{q}+(1-\pi_1)\underline{q}-\psi}{1-\delta} \geq \delta\frac{\pi_0\overline{q}+(1-\pi_0)\underline{q}}{1-\delta}, \text{ or}$$

$$\frac{\psi}{\pi_1-\pi_0} \leq \delta\frac{[\pi_1\overline{q}+(1-\pi_1)\underline{q}]-[\pi_0\overline{q}+(1-\pi_0)\underline{q}]-\psi}{1-\delta}$$

IV. Moral Hazard in Teams

Multiple agents: only the total **output of the team is observable and verifiable**

$n \geq 2$ agents, $a_i \geq 0$ is effort of agent i

$x(a_1,...,a_n)$ is the team's output (in monetary terms), continuous, strictly increasing and concave

$u_i(m_i, a_i) = m_i - c_i(a_i)$ is agent i's utility

m_i is monetary reward, $c_i(a_i)$ is continuous, strictly increasing and convex

Allocations of rewards and efforts: $\{(m_1,...,m_n),(a_1,...,a_n)\}$, $\sum_{i=1}^{n} m_i \leq x(a_1,...,a_n)$

Pareto efficient allocation (no other allocation gives each agent a greater payoff)

The allocation $\{(m_1^*,...,m_n^*),(a_1^*,...,a_n^*)\}$ is efficient if and only if $(a_1^*,...,a_n^*)$ maximizes the social surplus $W(a_1,...,a_n) = x(a_1,...,a_n) - \sum_{i=1}^{n} c_i(a_i)$, and budget is balanced, $\sum_{i=1}^{n} m_i^* = x(a_1^*,...,a_n^*)$.

(=>) Suppose that $\{(m_1^*,...,m_n^*),(a_1^*,...,a_n^*)\}$ maximizes $S(a_1,...,a_n)$ and no money burning. Consider another allocation $\{(m_1,...,m_n),(a_1,...,a_n)\}$ such that

$$u_i(m_i, a_i) = m_i - c_i(a_i) > m_i^* - c(a_i^*) = u(m_i^*, a_i^*) \text{ for all agents.}$$

Then it must be that

$$\sum_{i=1}^{n} m_i - c(a_i) \le x(a_1,...,a_n) - \sum_{i=1}^{n} c(a_i) \le x(a_1^*,...,a_n^*) - \sum_{i=1}^{n} c(a_i^*) = \sum_{i=1}^{n} m_i^* - c(a_i^*).$$

This yields a contradiction.

(<=) Now suppose that $\{(m_1^*,...,m_n^*),(a_1^*,...,a_n^*)\}$ does not maximize $S(a_1,...,a_n)$ or there is money burning. Then there exists $\{(m_1,...,m_n),(a_1,...,a_n)\}$ such that

$$D = x(a_1,...,a_n) - \sum_{i=1}^{n} c(a_i) - [\sum_{i=1}^{n} m_i^* - \sum_{i=1}^{n} c(a_i^*)] > 0.$$

Setting $m_i = m_i^* + c(a_i) - c(a_i^*) + \frac{D}{n} > 0$, each agent gets

$$u(m_i, a_i) = m_i^* - c(a_i^*) + \frac{D}{n} > m_i^* - c(a_i^*) = u(m_i^*, a_i^*) \text{ and}$$

$$\sum_{i=1}^{n} m_i = \sum_{i=1}^{n} m_i^* + c(a_i) - c(a_i^*) + \frac{D}{n} = x(a_1,...,a_n).$$

This yields a contradiction.

Incentives

Differentiable sharing rules $s_1(x(a_1,...,a_n)),...,s_n(x(a_1,...,a_n))$ that satisfy

$$\sum_{i=1}^{n} s_i(x(a_1,...,a_n)) = x(a_1,...,a_n)$$

Compensation can be negative

Each agent's payoff is

$$\pi_i(a_1,...,a_n) = s_i(x(a_1,...,a_n)) - c(a_i)$$

$(a_1^n,...,a_n^n)$ is Nash equilibrium if $\pi_i(a_i^n,.a_{-i}^n) \ge \pi_i(a_i\ ,a_{-i}^n)$ for all agents

Important Result Efficient allocation cannot be achieved in Nash equilibrium

Proof The optimality conditions for surplus maximization are

$$\frac{\partial W(a_1^*,...,a_n^*)}{\partial a_i} = \frac{\partial x(a_1^*,...,a_n^*)}{\partial a_i} - \frac{\partial c(a_i^*)}{\partial a_i} = 0.$$

The optimality conditions for each agent's problem are

$$\frac{\partial \pi_i(a_1^*,...,a_n^*)}{\partial a_i} = \frac{\partial s_i(x(a_1^*,...,a_n^*))}{\partial x}\frac{\partial x(a_1^*,...,a_n^*)}{\partial a_i} - \frac{\partial c(a_i^*)}{\partial a_i} = 0 .$$

Both are satisfied simultaneously only if $\frac{\partial s_i(x(a_1^*,...,a_n^*))}{\partial x} = 1$, or $\sum_{i=1}^{n}\frac{\partial s_i(x^*)}{\partial x} = n$.

Differentiating the budget constraint yields $\frac{\partial \sum_{i=1}^{n} s_i(x)}{\partial x} = \frac{\partial x}{\partial x} = 1$.

Under balanced budget, when the agent shirks, he saves the full cost, and loses only a share in the profit. For efficiency, we need to penalize all agents for the full consequence of their decision, but this is impossible when they always fully share the output

Efficient efforts can be implemented if money burning is feasible (non-balanced budget)

$\sum_{i=1}^{n} s_i(x(a_1,...,a_n)) \le x(a_1,...,a_n)$ is feasible

Consider the following sharing rule:

$$s_i(x) = \begin{cases} m_i, \text{ if } & x \ge x(a_1^*,...,a_n^*) \\ 0, \text{ if } & x < x(a_1^*,...,a_n^*) \end{cases},$$

where $m_i > c_i(a_i^*)$ and $\sum_{i=1}^{n} m_i = x(a_1^*,...,a_n^*)$

For any $x < x(a_1^*,...,a_n^*)$ the agents get less (nothing) than they produced

There is a Nash equilibrium each agent chooses a_i^* and the Pareto optimal outcome is attained

If $a_{-i} = (a_1,...,a_{i-1},a_{i+1},...,a_n) = (a_1^*,...,a_{i-1}^*,a_{i+1}^*,...,a_n^*)$

$a_i^* = \arg\max_a s_i(x(a_1^*,...,a_{i-1}^*,a,a_{i+1}^*,...,a_n^*)) - c(a)$ because

$$s_i(x(a_1^*,...,a_{i-1}^*,a_i^*,a_{i+1}^*,...,a_n^*)) - c(a_i^*) = m_i - c(a_i^*)$$

$s_i(x(a_1^*,...,a_{i-1}^*,a,a_{i+1}^*,...,a_n^*)) - c(a_i^*) = m_i - c(a) < m_i - c(a_i^*)$ for any $a > a_i^*$

$s_i(x(a_1^*,...,a_{i-1}^*,a,a_{i+1}^*,...,a_n^*)) - c(a_i^*) = 0 < m_i - c(a_i^*)$ for any $a < a_i^*$

The aggregate penalty deters individual free-riding

=> The role of the principal is to penalize shirking (keep the output when the agents shirk)

Nash equilibrium is not unique under this sharing rule:

$(a_1,..,,a_n) = (0,...,0)$ and zero output is also a Nash equilibrium

=> this is worse than the unique equilibrium under the balanced budget

Empirical analysis of moral hazard and non-verifiability problems using randomized control trials
"Impact of Third-party Contract Enforcement in Agricultural Markets—A Field Experiment in Vietnam"
by Christoph Saenger, Maximo Torero and Matin Qaim (AJAE, 2014)

1.1. Issue: small farmers – value chain – consumers, high-value products require coordination
Factors and decisions: contracts to coordinate (plus provision of inputs and credit)
Economic problem (incentives): contracts are not well enforced (specifics are of course important)
- farmers can cheat when they receive credit or inputs
- buyers can cheat when quality is graded

What is studied: Does an independent agency that can verify product quality increase farmer production intensity, output levels, farm household welfare?
Variable "Y": provision of quality
Variable "X": treatment with independent quality measurement
Treatment group: contract becomes enforced (previously unobservable quality attributes are now measured and verified by an independent and certified laboratory)
Control group: farmers continue to produce under the initial contract

1.2. Supply-Chain Architecture and the Standard Contract
Production
Milk is produced on specialized, small-scale farms
Crossbreed dairy cows are held in sheds all year round
Feed rations: forage produced on farms and purchased fodder from concentrate
Marketing
Farmers usually sell all milk to one dairy company
Alternative sales options are very limited
- little demand in local informal markets in rural areas (milk is perishable)

Supply chain
The raw milk goes to a local milk collection center (MCC)
MCC is supplied by about 100 farmers
MCC is operated by a private entrepreneur employed by the dairy processor (on commission)
MCC (1) collects and handles milk twice a day, (2) samples milk, (3) initial tests quality (through staff deployed by the dairy processor), (4) daily transports raw milk to company processing plants in urban centers, (5) administer weekly payments to farmers.

1.3. Theory of production decisions under contract
- country-wide standardized written agreement that determines how much milk of what quality is purchased at which price
- output price per unit of milk *p* received by farmers is a function of milk quality:

$p=f(\theta)$

- quality, θ, is a function of milk fat, total solid content, bacterial contamination, adulteration

$\theta=g(x)$

- input use, x, includes type and amount of fodder, level of effort
- quantity, q

1.4. How is quality measured and why there could be problems:
To assess milk composition (milk fat and total solid content), Vinamilk staff takes milk samples individually from the daily delivery of each farmer to the MCC

One sample per week from each farmer is randomly selected for further analysis with sophisticated laboratory methods in the dairy plant
Producers have unique identification numbers and are paid individually according to their own output (quantity q and quality θ)
The base price for top-quality milk is subject to harsh deductions if one or more of the quality parameters fall short of the requirements set by the company
One-tenth of a gram of milk fat below the threshold—a deviation far too small to be visually detected even by experienced farmers—can trigger financial penalties

2. Experimental Design and Implementation

2.1. What is the treatment?

Every treatment farmer received three non-transferable vouchers, each valid for one independent analysis of milk quality (milk fat and total solid)

In this study the treatment is somewhat complex …

Complicated third-party verification process

Vouchers were meant to be executed whenever eligible farmers challenged the testing results reported by Vinamilk. Providing farmers with third-party quality verification involved complex transport and testing logistics. For each milk sample obtained at the MCC under the original contract (hereafter A-sample), an additional identical sample (hereafter B-sample) had to be taken for each treatment farmer. The B-sample was sent to an independent and certified laboratory in HCMC, where it was stored. If a farmer executed a voucher, the B-sample was analyzed by the third-party laboratory, and the testing results were reported by mail to the farmer. This allowed the farmer to compare if the results based on the A-sample reported by Vinamilk are identical to the results of the corresponding B-sample provided by the independent laboratory.

Why treatment should affect Vinamilk?

While Vinamilk knew the identity of the treatment farmers, the actual execution of vouchers could not be observed, i.e., the company did not know when an individual farmer in the treatment group executed her voucher. Hence, there was a constant threat to the company that any of the farmers in the treatment group could in any given week verify their testing result and detect potential opportunistic behavior. The combination of a constant threat to be caught and the associated high reputational costs, should effectively discourage Vinamilk from behaving opportunistically. This is a central assumption in this study and crucial for the intervention to work; more about this later.

Why not test every milk sample?

Compared to validating the results of every sample analyzed by Vinamilk, the voucher mechanism enabled us to systematically overcome the information asymmetry on milk quality attributes at relatively low cost. All outlays arising from setting up a parallel testing infrastructure for the B-samples and milk analyses were borne by the project, ruling out that farmers would not request independent milk testing for reasons of monetary costs.

Additional considerations

Did treated farmers understand the procedure? During a compulsory half-day workshop, treatment farmers were informed about the independent milk testing and learned how to use the vouchers. Every treatment farmer received written instructions, supplementing the information presented during the workshop, and was provided with a phone number of trained field staff.

Did treated farmers trust the independent verification? Both farmers and Vinamilk explicitly agreed on a certified laboratory.

Were samples taken by Vinamilk and third-party identical? The third-party laboratory and Vinamilk's in-house laboratory were calibrated using imported reference milk. By employing the same cooling technology we also assured that during transport and storage the A- and B-samples were kept in identical environments.

Compliance with treatment

How to ensure that control group farmers do not get access to the third-party milk testing and thus effectively become treated?

- personalized vouchers with a unique identification number
- vouchers passed on to other farmers automatically became invalid
- control farmers do not sell their milk through treatment farmers

(1. to maintain traceability within the milk supply chain, milk producers register their herd size with Vinamilk, quantity potential is known, 2. mixing milk with another's farmer's milk of unknown quality)

Low uptake of voluntary treatment

- mandatory treatment
- low rate of execution of verification vouchers is sufficient for treatment to work

2.2. Study Area, Sample, and Randomization

- 402 dairy farmers that are contracted by Vinamilk
- 4 MCCs

Table A1: Summary Statistics of Selected Variables by Milk Collection Center (MCC)

	MCC A (n=113)	MCC B (n=103)	MCC C (n=86)	MCC D (n=83)
HH characteristics				
No. of HH members	4.513	4.641	4.244	4.341
	[1.536]	[1.514]	[1.255]	[1.399]
Age of HH head	45.46	44.66	47.61	47.38
	[11.53]	[9.161]	[11.74]	[11.39]
Total HH income (VND)	74,192,179	82,514,741	67,618,558	73,970,047
	[49,567,765]	[69,491,153]	[58,362,681]	[53,442,489]
Dairy income (VND)	45,968,059	53,551,420	44,313,419	52,171,927
	[35,675,422]	[55,525,486]	[53,633,181]	[47,796,603]
Dairy production				
Herd size (heads)	7.611	8.194	7.744	6.398
	[5.417]	[5.369]	[4.587]	[3.751]
Productivity per cow (kg)	4,051.6	4,925.9*	4,477.3	n.a.
	[2,888.4]	[2,229.7]	[2,472.7]	
Average milk price (VND)	6,850.0	6,730.9**	6,542.4***	6,671.4*
	[275.6]	[294.7]	[416.7]	[772.3]
Total solid (%)	12.63	12.50	12.35***	12.61
	[0.520]	[0.496]	[0.427]	[0.641]
Milk fat (%)	3.980	3.907*	3.862**	4.074
	[0.280]	[0.245]	[0.221]	[0.482]
Milk hygiene score	3.572	3.642	3.686**	3.578
	[0.368]	[0.205]	[0.162]	[0.465]

Notes: Mean values are shown with standard deviations in brackets. HH means household. MCC means milk collection center. VND means Vietnamese Dong. Mean differences are tested for MCC B – MCC A, MCC C – MCC A, and MCC D – MCC C. *p<0.1, **p<0.05, ***p<0.01.

- differences in output and quality across MCC
- MCCs B, C and D are spatially clustered and farmers can choose
- MCC A has a competitor
- MCC dummies account for MCC-specifc effects (trust, location, etc)
- randomization at MCC level is not possible due to small number of MCCs
- randomization over 402 dairy farmers
- in May 2009, all farmers attended a public lottery in which 102 farmers were randomly assigned to the treatment group (with vouchers)
- another 100 farmers were randomly assigned to the control group (without vouchers)
- intervention started in May 2010 and continued for 12 months

2.3. Data

-2 rounds of **structured household surveys**: socioeconomic details on dairy production, income from agricultural and non-agricultural activities, household expenditures, and assets owned, questions measuring social capital, trust, time and risk preferences

    - May 2009 before the experiment started

- May and June 2011, after the experiment was completed

- **farm-level output data provided by Vinamilk**
    - May 2008 to May 2011
- self-reported recall data on output from household surveys is **not precise**
- weekly reported information (milk quantity and three quality parameters) is the basis for farmers' payment is very precise but may include **underreporting before the experiment by Vinamilk**

3. Identification Strategy and Econometric Estimation

The impact of third-party quality verification is assessed in three dimensions:

- (a) input use in milk production:
  amount of purchased fodder used per cow and day reported by farmers
- (b) output (quantity and quality) generation in milk production:
  total amount of milk fat and total solid produced during the twelve months, revenues from dairy farming
- (c) welfare of the farming household:
  total annual household consumption expenditures on food (own produced food items were valued at the market price), other consumer goods, and durables obtained through the household surveys

3.1. Identification of two types of treatment effects

I. Average treatment effect on the treated (ATT):

$$ATT = E[Y(1) - Y(0) \mid X = 1]$$

$E[Y(1) \mid X = 1]$ - average outcome of the treated

$E[Y(0) \mid X = 1]$ - counterfactual outcome of the untreated, conditioned on the treatment status $X = 1$

$X \in \{0,1\}$ is randomly assigned

To estimate ATT, specify an OLS according to

$$Y = \beta_0 + \beta_1 X + u$$

where Y is ATT and X is treatment dummy

II. Heterogeneous treatment effect

$$ATT(W) = E[Y(1) - Y(0) \mid X = 1, W]$$

$$Y = \beta_0 + \beta_1 X + \beta_2 W + \beta_3 XW + u$$

use interaction term to test the effect of baseline characteristics on ATT

- "trust towards Vinamilk" (W=1 if farmers agreed with the statement "Vinamilk is a trustworthy business partner" in the baseline survey, and 0 otherwise)
- MCC-specific dummies

3.2. Randomization

Are treatment and control groups similar statistically with respect to observables from the baseline survey?

Table 1: Mean Difference for Baseline Variables in Treatment and Control Groups

	Control -Voucher	Standard Error
Basic household characteristics		
Age of HH-head (in yrs)	1.233	1.558
Education HH head (in yrs of schooling)	0.556	0.442
Number of HH member	0.073	0.183
Total land size (in m²)	893	783
Distance to paved road (in km)	0.270*	0.122
If agree to postpone at interest rate <= 3.5% (1=y)	-0.183**	0.069
Dairy enterprise		
Delivers milk to MCC A (1=y)	0.033	0.063
Delivers milk to MCC B (1=y)	-0.098	0.064
Delivers milk to MCC C (1=y)	0.065	0.065
Delivers milk to MCC D (1=y)	-0.000	0.065
Daily concentrate per cow (in kg)	1.626	1.826
Absolute milk fat (in kg)	-53.519	59.996
Absolute total solid (in kg)	-173.342	194.658
Annual revenue from dairy (in USD)	-432.499	550.234
Household expenditure		
Annual HH expenditure (in USD)	36.410	111.463

Notes: HH means household. MCC means milk collection center. *p<0.1, **p<0.05.

3.3. Attrition

- attrition rate is balanced between treatment and control groups
- number of households in the treatment and control group decreased from 102 and 100 to 94 and 90
- smaller herds, less productive farmers were more likely to exit

3.4. Compliance

- intervention did not require high compliance rates
- 7 farmers out of 94 requested independent verification of milk testing
- larger herd sizes, more productive dairy cows on average
- 50% did not feel it was necessary
- 40% felt uneasy
- free-riding is likely
- all individuals assigned to the treatment group (except for dropouts) can be regarded as treated

4. Estimation Results

Table 2: Estimation Results for Input Use and Output Produced

	Input			Output					
	Daily concentrate per cow(in kg)			Absolute milk fat (in kg)			Absolute total solid (in kg)		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Voucher treatment (1=y)	0.826**	0.869**	0.973*	71.3	119.1	289.7**	227.6	387.8	913.9**
	[0.365]	[0.414]	[0.512]	[80.4]	[111.1]	[136.9]	[249.5]	[344.1]	[433.4]
Trust towards Vinamilk (1=y)		-0.020			157.6			505.5	
		[0.369]			[141.5]			[448.0]	
Vinamilk trust * Voucher		-0.033			-82.0			-279.7	
		[0.566]			[165.8]			[515.8]	
MCC B (1=y)			-0.935*			212.8			683.3
			[0.504]			[134.5]			[425.7]
MCC C (1=y)			-0.847			29.5			105.6
			[0.541]			[151.7]			[480.1]
MCC D (1=y)			0.136			110.3			367.7
			[0.541]			[144.9]			[458.6]
MCC B * Voucher			0.271			-154.8			-522.8
			[0.701]			[193.4]			[611.9]
MCC C * Voucher			-1.059			-271.9			-829.2
			[0.709]			[198.5]			[628.3]
MCC D * Voucher			0.088			-363.7*			-1,139*
			[0.720]			[197.0]			[623.5]
Constant	6.905***	6.915***	7.375***	515.2***	443.2***	415.2***	1,630***	1,399***	1,304***
	[0.284]	[0.399]	[0.393]	[53.3]	[54.98]	[101.1]	[170.3]	[167.9]	[320.1]
Observations [a]	164	162	164	172	170	172	172	170	172
R-squared	0.056	0.060	0.221	0.006	0.025	0.071	0.006	0.026	0.066

Notes: Robust standard errors, clustered at MCC level, in brackets. MCC means milk collection center. *p<0.1, **p<0.05, ***p<0.01.
[a] The number of observations varies across models because of missing values for some of the variables. We also ran alternative estimates with equal number of observations across models, excluding farmers with missing values throughout. The results are very similar (see table A2 in the annex).

4.1. Fodder concentrate (main input/milk quality)
- significant positive treatment effect
- robust across specifications
- farmers in the treatment group on average fed 12% more
- no "trust" effect on treatment
- no treatment effects on other inputs: labor input, veterinary services, and artificial insemination

Milk quantity
- insignificant without controlling for other covariates
- significant if control for MCC affiliation
- interesting MMC's effects (center A has a competitor, B,C,D are clustered)

Joint quantity and quality output function
- fat and solid content **per** kg of milk as dependent variables
- no significant treatment effects
- why?
- physiology of dairy cows: increase in concentrate use leads to higher milk quantity produced per cow, not higher fat and solid content per kg of milk….

4.2. Revenue effects

Table 3: Estimation Results for Revenue and Household Welfare

	Revenue Annual from dairy (in USD)			Welfare Annual HH expenditure (in USD)		
	(1)	(2)	(3)	(4)	(5)	(6)
Voucher treatment (1=y)	812.8	1,446	3,164*	82.95	-733.6	153.5
	[830.7]	[1,179]	[1,659]	[375.0]	[358.9]	[931.4]
Trust towards Vinamilk (1=y)		1,940			-661.5	
		[1,725]			[390.0]	
Vinamilk trust * Voucher		-1,119			1,731**	
		[1,855]			[363.4]	
MCC B (1=y)			3,173*			-63.94
			[1,629]			[907.6]
MCC C (1=y)			874.4			-344.6
			[1,837]			[972.8]
MCC D (1=y)			1,931			-778.6
			[1,755]			[940.5]
MCC B * Voucher			-1,825			-1,185
			[2,342]			[1,310]
MCC C * Voucher			-2,704			658.8
			[2,404]			[1,300]
MCC D * Voucher			-3,859			-17.20
			[2,386]			[1,294]
Constant	6,118***	5,232***	4,474***	4,106***	4,400***	4,401***
	[762.3]	[693.1]	[1,225]	[181.2]	[316.6]	[687.9]
Observations [a]	172	170	172	184	182	184
R-squared	0.005	0.025	0.060	0.000	0.021	0.026

Note: Robust standard errors, clustered at MCC level, in brackets. MCC means milk collection center. *p<0.1, **p<0.05, ***p<0.01.
[a] The number of observations varies across models because of missing values for some of the variables. We also ran alternative estimates with equal number of observations across models, excluding farmers with missing values throughout. The results are very similar (see table A3 in the annex).

- positive but insignificant without controls
- heterogeneous treatment effect with respect to milk collection center affiliation
- milk quality was not affected by the treatment
- average price received remained unchanged
- the increment in revenue can entirely be attributed to increased production quantity

4.3. Welfare

- overall no significant impact on total household consumption expenditures (very short period)
- significant if control for trust (if long-term commitment by the company makes consumption less risky)

5. Robustness checks

Contamination

- spillovers if communication between treated and untreated neighbors (follow-up survey on trust)
- systematic differences between MCCs make MCC-level randomization problematic

Data Provision and Incentive Compatibility by Vinamilk

- attribute treatment effects to behavioral change of farmers
- did Vinamilk's reporting behavior change after treatment?
- output (quantity and quality) *reported* by Vinamilk vs *true* output obtained using laboratory methods
- quality did not change after treatment
- Vinamilk provided data on quality over a long period before the treatment