Contracts and Technology Adoption

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Introduction

• Broad consensus that differences in total factor productivity ("efficiency") account for a major part of the large cross-country differences in living standards (e.g., Klenow and Rodriguez, 1997, Hall and Jones, 1999, Caselli, 2004).

• We are far, however, from a consensus on the causes of these differences in TFP.

• Obvious approach: different countries have access to different technologies. But difficult to motivate in a world with (almost) free flow of ideas and machines embedding the latest technologies.

• This paper develops a simple theory where differences in contracting institutions affect technology adoption decisions of firms and thereby generate cross-country productivity and income differences.
Main Ingredients of the Model: Building Blocks

- Partial-equilibrium model in which a firm decides on the adoption of a particular production technology, with more advanced technologies being associated with greater productivity.

- Our key assumption is that more advanced technologies are associated with more specialization, in the Ethier (1982), Romer (1987), Grossman and Helpman (1991) sense of using more intermediate inputs.

- Thus a greater degree of specialization (more advanced technologies) requires the firm to contract with more suppliers.

- In the presence of contractual frictions, adopting the most advanced technologies may not be optimal.
Main Ingredients of the Model: Contractual Frictions

- A fraction of the relationship-specific activities performed by suppliers are not ex ante contractible (lack of third-party verifiability).

- Contracting difficulties lead to an ex post multilateral bargaining problem between the firm and its suppliers: firm cannot commit not to hold up its suppliers.

- Hold up reduces incentives of suppliers to invest in non-contractible activities.

- We adopt the Shapley value as the solution concept for multilateral bargaining.

- We show that the degree of complementarity between inputs in production plays a crucial role in determining the payoffs of this game (simple reduced form bargaining weights).
Main Results

• We show that firms in countries with worse contractual institutions adopt relatively less advanced technologies (featuring a lower degree of specialization).

• Contracting problems have a more negative effect on productivity when inputs are more complementary.

• Effect can be quantitatively large.

• The simple form of the equilibrium profit function we derive can be used in various general equilibrium applications. Here we study:
  - economy-wide improvement in the contracting environment (aggregate resource constraints lead to relocation effects);
  - trade opening with a country with different institutions (institutions emerge as a source of comparative advantage).
Related Literature

• Specialization and the extent of the market: Adam Smith, Young (1928), Yang and Borland (1991), as well as new monopolistic competition and product-variety growth models, Dixit-Stiglitz, Romer, Grossman-Helpman.


Model

- A firm faces demand curve with $\beta \in (0, 1)$:
  \[ q = Ap^{-1/(1-\beta)}, \]

- Revenue from producing a quantity $q$:
  \[ R(q) = A^{1-\beta}q^\beta \tag{1} \]

- Production when the firm adopts technology $N$ is:
  \[ q = N^{\kappa+1-1/\alpha} \left[ \int_0^N X(j)^\alpha \, dj \right]^{1/\alpha}, \quad 0 < \alpha < 1 \tag{2} \]

  where $X(j)$ is an input of type $j$.

- $\alpha$: the degree of substitutability between inputs.

- When $X(j) = X$, then $q = N^{\kappa+1}X$, so greater $N$ translates into greater productivity.
Technology

- Key assumption: each input is performed by a different supplier, with whom the firm needs to contract.
- One can derive this mapping between suppliers and inputs as an outcome of a richer model that incorporates diseconomies of scope.
- Each supplier has an outside option equal to $w_0$.
- Each supplier needs to perform a unit measure of symmetric activities, each entailing a marginal cost $c_x$:

$$X(j) = \exp \left[ \int_0^1 \ln x(i,j) \, di \right], \quad (3)$$

where $x(i,j)$ denotes the services from activity $i$ performed by the supplier in charge of input $j$. 
Technology (continued)

- Technology adoption is costly, and denote the cost of adopting technology \( N \) by \( C(N) \).

- For second-order conditions and to ensure an interior solution, we make the following regularity assumption:

**Assumption 1**

(i) For all \( N > 0 \), \( C(N) \) is twice continuously differentiable, with \( C'(N) > 0 \) and \( C''(N) \geq 0 \).

(ii) For all \( N > 0 \),
\[
NC''(N) / [C'(N) + w_0] > [\beta(\kappa + 1) - 1] / (1 - \beta).
\]
Payoffs

• The firm and the suppliers maximize their payoff.

• Payoff to supplier $j$ (taking account of outside option) is

$$\pi_x(j) = \max \left\{ \tau(j) + s(j) - \int_0^1 c_x(i, j) di, w_0 \right\}. \quad (4)$$

where $\tau(j)$ is an ex ante payment that can be negative, and $s(j)$ is an ex post payment.

• Payoff of the firm is

$$\pi = R - \int_0^N \left[ \tau(j) + s(j) \right] dj - C(N), \quad (5)$$

where $R$ is revenue.
Technology Adoption with Complete Contracts

- With complete contracts, the firm chooses $N$ and makes offer
  
  \[
  \{ x(i,j) \}_{i\in[0,1], j\in[0,N]}, \{ s(j), \tau(j) \}_{j\in[0,N]} \]

  to suppliers.

- The subgame perfect equilibrium maximizes:

  \[
  A^{1-\beta} N^{\beta(\kappa+1-1/\alpha)} \left[ \int_0^N \left( \exp \left( \int_0^1 \ln x(i,j) \, di \right) \right)^\alpha \, dj \right]^{\beta/\alpha} \\
  - \int_0^N [\tau(j) + s(j)] \, dj - C(N)
  \]

  \[
  s(j) + \tau(j) - c_x \int_0^1 x(i,j) \, di \geq w_0 \text{ for all } j \in [0, N]. \tag{6}
  \]
Proposition 1 Suppose that Assumption 1 holds. Then with complete contracting there exists a unique equilibrium $x^* > 0$, $N^* > 0$ and $P^* > 0$. Furthermore, this solution satisfies

\[
\frac{\partial N^*}{\partial A} > 0, \quad \frac{\partial x^*}{\partial A} \geq 0, \quad \frac{\partial P^*}{\partial A} > 0, \quad \frac{\partial N^*}{\partial \alpha} = \frac{\partial x^*}{\partial \alpha} = \frac{\partial P^*}{\partial \alpha} = 0.
\]

- No effect of the degree of complementarity, $\alpha$, on technology or productivity.
- As in Smith, the size of the market, $A$, affects the degree of specialization and productivity.
Contractual Structure

• Incomplete contracts: only investments in activities $i \in [0, \mu]$ are observable and verifiable.

• So complete contracts—specifying the amount of investment/services to be delivered—can be written for the services of activities $i \in [0, \mu]$. These can be enforced by a court of law.

• For the remaining $1 - \mu$ activities, the $x(i, j)$s are not verifiable, so no contracts are possible (see Grossman and Hart, 1986, Hart and Moore, 1990).

• Assume perfect capital markets, so ex ante transfers are possible.
Ex Post Bargaining

- Ex-post distribution of revenue is governed by multilateral bargaining: use Shapley value as the solution concept for the multilateral bargaining game (more on this below).

- The threat point of each supplier in bargaining is not to provide the services for the non-contractible activities.

- Ex post bargaining determines suppliers’ investment incentives, and through this channel, the productivity gains from adopting alternative technologies.
The Timing of Events

- The timing of events is:
  1. The firm chooses $N$ and offers $\{[x_c(i,j)]_{i=0}^{\mu}, \tau(j)\}$ for every $j \in [0,N]$.
  2. The firm chooses $N$ suppliers from a pool of applicants, one for each input $j$.
  3. Suppliers $j \in [0,N]$ simultaneously choose investment levels $x(i,j)$ for all $i \in [0,1]$. In the contractible activities $i \in [0,\mu]$ they invest $x(i,j) = x_c(i,j)$ for every $j$.
  4. The suppliers and the firm bargain over the division of revenue.
  5. Output is produced and sold, and the revenue $R(q)$ is distributed according to the bargaining agreement.
Technology Adoption with Incomplete Contracts

- Symmetric subgame perfect equilibrium, where the bargaining outcomes in all subgames are determined by Shapley values.

- Solve by backwards induction.

- In the bargaining, $N, x_c$ and $x_n$ are given. The available revenue is $A^{1-\beta} (N^{\kappa+1} x_c^{\mu} x_n^{1-\mu})^\beta$, and is distributed according to their Shapley values.

- Let $s_x (N, x_c, x_n)$ denote the Shapley value of a representative supplier and by $s_q (N, x_c, x_n)$ the Shapley value of the firm, where

\[
s_q (N, x_c, x_n) + N s_x (N, x_c, x_n) = A^{1-\beta} (N^{\kappa+1} x_c^{\mu} x_n^{1-\mu})^\beta.
\]
Technology Adoption with Incomplete Contracts (continued)

• For $N$ and $x_c$ given, suppliers choose:

$$x_n \in \arg \max_{x_n(j)} \bar{s}_x [N, x_c, x_n (-j), x_n (j)] - (1 - \mu) c_x x_n (j), \quad (7)$$

where $\bar{s}_x (\cdot)$ is such that $s_x (N, x_c, x_n) = \bar{s}_x (N, x_c, x_n, x_n)$.

• After imposing participation constraint, we find that firm solves

$$\max_{N, x_c, x_n} s_q (N, x_c, x_n)$$

$$+ N [\bar{s}_x (N, x_c, x_n, x_n) - \mu c_x x_c - (1 - \mu) c_x x_n] - C (N) - w_0 N$$

subject to (7). \quad (8)$$
The Shapley Value

- We adopt the Shapley value to determine $s_q (N, x_c, x_n)$ and $\bar{s}_x [N, x_c, x_n, x_n (j)]$.

- The Shapley value of a player is the average of his contributions to all coalitions that consist of players ordered below him in all feasible permutations.

- Problem: Shapley value defined for games with a discrete number of players.

- Here we consider the limit of a finite-player game to obtain a tractable expression for the Shapley value.

- This is similar to the approach in Aumann and Shapley (1974) and Stole and Zwiebel (1996a,b).
The Shapley Value (continued)

**Lemma 1** Suppose that $M \rightarrow \infty$, and supplier $j$ invests $x_n(j)$ in her noncontractible activities, all the other suppliers invest $x_n(-j)$ in their noncontractible activities, every supplier invests $x_c$ in contractible activities, and technology $N$ has been adopted. Then the Shapley value of a supplier $j$ is

$$\bar{s}_x [N, x_c, x_n(-j), x_n(j)] = (1 - \gamma) A^{1-\beta} \left[ \frac{x_n(j)}{x_n(-j)} \right]^{(1-\mu)\alpha}$$

$$\times x_c^{\beta \mu} x_n(-j)^{\beta (1-\mu)} N^{\beta (\kappa+1)-1}, \quad (9)$$

where

$$\gamma \equiv \frac{\alpha}{\alpha + \beta}. \quad (10)$$
The Shapley Value (continued)

- In a symmetric equilibrium:

\[
s_x(N, x_c, x_n) = (1 - \gamma) A^{1-\beta} x_c^\beta \mu x_n^{\beta(1-\mu)} N^{\beta(\kappa+1) - 1} = (1 - \gamma) \frac{R}{N}.
\]

and

\[
s_q(N, x_c, x_n) = \gamma A^{1-\beta} x_c^\beta \mu x_n^{\beta(1-\mu)} N^{\beta(\kappa+1)} = \gamma R. \tag{11}
\]

- \(\gamma = \alpha / (\alpha + \beta)\): bargaining power of the firm, increasing in input substitutability \(\alpha\) and declining in \(\beta\).

- The concavity of \(s_x [N, x_c, x_n (-j), x_n (j)]\) with respect to noncontractible activities \(x_n (j)\) depends on \(\alpha\) but not on \(\beta\).
  - concavity of private return arises only from the complementarity between different inputs rather than from the concavity of the revenue function in output.
Incomplete Contracts Equilibrium (continued)

**Proposition 2** Suppose that Assumption 1 holds. Then there exists a unique SSPE with $\tilde{N}, \tilde{x}_c, \tilde{x}_n > 0$, and an associated productivity level $\tilde{P} > 0$. Furthermore, $\left(\tilde{N}, \tilde{x}_c, \tilde{x}_n, \tilde{P}\right)$ satisfies

$$\tilde{x}_n < \tilde{x}_c$$

and

$$\frac{\partial \tilde{N}}{\partial A} > 0, \quad \frac{\partial \tilde{x}_c}{\partial A} \geq 0, \quad \frac{\partial \tilde{x}_n}{\partial A} \geq 0, \quad \frac{\partial \tilde{P}}{\partial A} > 0,$$

(12)

$$\frac{\partial \tilde{N}}{\partial \mu} > 0, \quad \frac{\partial \tilde{x}_c}{\partial \mu} \geq 0, \quad \frac{\partial (\tilde{x}_n/\tilde{x}_c)}{\partial \mu} > 0, \quad \frac{\partial \tilde{P}}{\partial \mu} > 0,$$

(13)

$$\frac{\partial \tilde{N}}{\partial \alpha} > 0, \quad \frac{\partial \tilde{x}_c}{\partial \alpha} \geq 0, \quad \frac{\partial (\tilde{x}_n/\tilde{x}_c)}{\partial \alpha} > 0, \quad \frac{\partial \tilde{P}}{\partial \alpha} > 0.$$ 

(14)
Incomplete Contracts Equilibrium (continued)

• The profit function of the firm can be expressed as:

$$\pi = AZ(\alpha, \mu) N^{1+\frac{\beta(k+1)-1}{1-\beta}} - C(N) - w_0 N,$$

where

$$Z(\alpha, \mu) \equiv (1 - \beta) \beta^{\frac{\beta \mu}{1-\beta}} \left[ \alpha (1 - \gamma) \right]^{\frac{\beta(1-\mu)}{1-\beta}}$$

$$\times \left[ \frac{1 - \alpha (1 - \gamma) (1 - \mu)}{1 - \beta (1 - \mu)} \right]^{\frac{1-\beta(1-\mu)}{1-\beta}} (c_x)^{-\frac{\beta}{1-\beta}}$$

• The term $Z(\alpha, \mu)$ captures ”distortions” arising from incomplete contracting.
Incomplete Contracts Equilibrium (continued)

- We can also establish that:

**Lemma 2** Suppose that Assumption 1 holds. Let \( \zeta_\mu (\alpha, \mu) \equiv (\mu \times \partial Z (\alpha, \mu) / \partial \mu) / Z (\alpha, \mu) \) be the elasticity of \( Z (\alpha, \mu) \) with respect to \( \mu \) and let let \( \zeta_\alpha (\alpha, \mu) \equiv (\alpha \times \partial Z (\alpha, \mu) / \partial \alpha) / Z (\alpha, \mu) \) be the elasticity of \( Z (\alpha, \mu) \) with respect to \( \alpha \). Then, we have that

1. \( \zeta_\mu (\alpha, \mu) > 0 \) and \( \zeta_\alpha (\alpha, \mu) > 0 \); and
2. \( \partial \zeta_\mu (\alpha, \mu) / \partial \alpha < 0 \) and \( \partial \zeta_\alpha (\alpha, \mu) / \partial \mu < 0 \).

- Interestingly, the effect of incomplete contracts is more severe on sectors with greater complementarities. This is crucial for the general equilibrium applications below.
Quantitative Exercise

• Consider the ratio of productivity in two economies with the fraction of contractible tasks given by $\mu_1$ and $\mu_0 < \mu_1$,

\[
\frac{\tilde{P}(\mu_1)}{\tilde{P}(\mu_0)} = \left[\frac{1-\alpha(1-\gamma)(1-\mu_1)}{1-\beta(1-\mu_1)}\right]^{\frac{\kappa(1-\beta(1-\mu_1))}{1-\beta(\kappa+1)}} \left[\frac{1-\alpha(1-\gamma)(1-\mu_0)}{1-\beta(1-\mu_0)}\right]^{\frac{\kappa(1-\beta(1-\mu_0))}{1-\beta(\kappa+1)}} \left[\beta^{-1}\alpha (1 - \gamma)\right]^{\frac{\kappa\beta(\mu_0-\mu_1)}{1-\beta(\kappa+1)}},
\]

(16)

• Parameter $\beta$ related to substitutability of final goods and to markups. Both types of evidence suggest a $\beta$ around 0.75.

• We choose $\kappa$ to match Bils and Klenow’s (2001) estimates of variety growth in the US economy from BLS data on expenditures on different types of goods. Yields $\kappa \simeq 0.25$. 
Figure 1: Relative productivity for $\beta = 0.75$ and $\kappa = 0.25$
Figure 2: Relative productivity $\bar{P}(0.75) / \bar{P}(0.25)$ for $\kappa = 0.25$ and alternative $\beta$'s.
Figure 3: Relative productivity $\tilde{P}(0.75)/\tilde{P}(0.25)$ for $\beta = 0.75$ and alternative $\kappa$'s.
Extensions and Applications: Vertical Integration Versus Outsourcing

- Can other features of organizations alleviate the constraints that contracting problems place on technology adoption?

- Here we consider the choice between vertical integration versus outsourcing.

- As in Grossman-Hart-Moore, the organizational form (allocation of physical assets) affects the threat point of agents in the bargaining.

- Without transfers, vertical integration is potentially useful, as a way of extracting surplus from suppliers more efficiently than forcing them to overinvest.

- Vertical integration is relatively more attractive when complementarity between inputs is high.
Extensions and Applications: General Equilibrium

- The simple form of the equilibrium profit function we derive can be used in various general equilibrium applications, which incorporate an aggregate resource constraint.

- Assume that there exists a continuum of final goods $q(z)$, with $z \in [0, Q]$, each produced by a different firm. Firms vary in their $\alpha$’s.

- Labor is in fixed supply $L$. Since $NQ$ individuals serve as suppliers, the residual supply of labor for other activities is $L - NQ$. Only other employment is the process of adoption (implementation, use, or perhaps creation) of technologies. Adopting a technology $N$ requires $C_L(N)$ units of labor.

- The wage rate $w$ is taken as given by each firm, but is endogenously determined in equilibrium.
Extensions and Applications: General Equilibrium

- An economy-wide improvement in the contracting environment leads to relocation effects; sectors with higher levels of complementarity expand, while sectors with lower levels of complementarity contract.

- In a two-country setup in which countries differ only in their contractual institutions, institutions emerge as a source of comparative advantage; countries with better institutions specialize in sectors with high complementarities.
Conclusions

- We have developed a tractable framework for the analysis of the impact of contracting institutions and technological complementarities on equilibrium technology adoption.

- We view our model as a starting point for an analysis of the relationship between contracting institutions and productivity across countries.
  - Despite increasing evidence that differences in TFP are an important element of cross-country differences in income per capita, we are far from a theory of productivity differences.
  - Our model leads to both endogenous differences in the ”technology” of production (as measured by N) and in the efficiency with which a given technology is used.