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.
- Incomplete contracting and the boundaries of the firm: Klein, Crawford and Alchian (1978), Williamson (1985), Grossman and Hart (1986), Hart and Moore (1990), Stole and Zwiebel (1996a,b), Aghion and Tirole (1997).
- Growth and Institutions: Acemoglu and Zilibotti (1999), Martimort and Verdier (2000, 2004), Francois and Roberts (2003).
- Trade and Institutions: Levchenko (2003), Costinot (2004), Nunn (2004) and Antràs (2005).

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:

$$q = N^{\kappa+1-1/\alpha} \left[\int_0^N X(j)^{\alpha} \, dj \right]^{1/\alpha}, \;\; 0 < \alpha < 1 \tag{2}$$

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

- α: 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:

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

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

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

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

$$\pi = R - \int_0^N [\tau(j) + s(j)]\, dj - C(N), \tag{5}$$

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:

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

$$s(j) + \tau(j) - c_x \int_0^1 x(i,j)\, di \geq w_0 \text{ for all } j \in [0,N]. \qquad (6)$$

Technology Adoption with Complete Contracts (continued)

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

$$\frac{\partial N^*}{\partial A} > 0, \; \frac{\partial x^*}{\partial A} \geq 0, \; \frac{\partial P^*}{\partial A} > 0, \; \frac{\partial N^*}{\partial \alpha} = \frac{\partial x^*}{\partial \alpha} = \frac{\partial P^*}{\partial \alpha} = 0.$$

- No effect of the degree of complementarity, α, 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 $A^{1-\beta}\left(N^{\kappa+1}x_c^{\mu}x_n^{1-\mu}\right)^{\beta}$, 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

$$s_q(N, x_c, x_n) + N s_x(N, x_c, x_n) = A^{1-\beta}\left(N^{\kappa+1}x_c^{\mu}x_n^{1-\mu}\right)^{\beta}.$$

Technology Adoption with Incomplete Contracts (continued)

- For N and x_c given, suppliers choose:

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

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

- After imposing participation constraint, we find that firm solves

$$\max_{N, x_c, x_n} s_q(N, x_c, x_n)$$
$$+ N\left[\overline{s}_x(N, x_c, x_n, x_n) - \mu c_x x_c - (1-\mu)\, c_x x_n\right] - C(N) - w_0 N$$
$$\text{subject to (7)}. \quad (8)$$

The Shapley Value

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

$$\bar{s}_x\left[N, x_c, x_n(-j), x_n(j)\right] = (1-\gamma) A^{1-\beta}\left[\frac{x_n(j)}{x_n(-j)}\right]^{(1-\mu)\alpha} \times x_c^{\beta\mu} x_n(-j)^{\beta(1-\mu)} N^{\beta(\kappa+1)-1}, \qquad (9)$$

where

$$\gamma \equiv \frac{\alpha}{\alpha+\beta}. \qquad (10)$$

The Shapley Value (continued)

- In a symmetric equilibrium:

$$\begin{aligned} s_x(N, x_c, x_n) &= (1-\gamma) A^{1-\beta} x_c^{\beta\mu} x_n^{\beta(1-\mu)} N^{\beta(\kappa+1)-1} \\ &= (1-\gamma) \frac{R}{N}. \end{aligned}$$

  and

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

- $\gamma = \alpha/(\alpha+\beta)$: bargaining power of the firm, increasing in input substitutability α and declining in β.
- The concavity of $\bar{s}_x[N, x_c, x_n(-j), x_n(j)]$ with respect to noncontractible activities $x_n(j)$ depends on α but not on β.
  - 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

$$\frac{\partial \tilde{N}}{\partial A} > 0, \ \frac{\partial \tilde{x}_c}{\partial A} \geq 0, \ \frac{\partial \tilde{x}_n}{\partial A} \geq 0, \ \frac{\partial \tilde{P}}{\partial A} > 0, \tag{12}$$

$$\frac{\partial \tilde{N}}{\partial \mu} > 0, \ \frac{\partial \tilde{x}_c}{\partial \mu} \geq 0, \ \frac{\partial \left(\tilde{x}_n / \tilde{x}_c\right)}{\partial \mu} > 0, \ \frac{\partial \tilde{P}}{\partial \mu} > 0, \tag{13}$$

$$\frac{\partial \tilde{N}}{\partial \alpha} > 0, \ \frac{\partial \tilde{x}_c}{\partial \alpha} \geq 0, \ \frac{\partial \left(\tilde{x}_n / \tilde{x}_c\right)}{\partial \alpha} > 0, \ \frac{\partial \tilde{P}}{\partial \alpha} > 0. \tag{14}$$

Incomplete Contracts Equilibrium (continued)

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

$$\pi = AZ(\alpha, \mu) N^{1+\frac{\beta(\kappa+1)-1}{1-\beta}} - C(N) - w_0 N, \tag{15}$$

where

$$\begin{aligned} Z(\alpha, \mu) &\equiv (1-\beta)\beta^{\frac{\beta\mu}{1-\beta}} [\alpha(1-\gamma)]^{\frac{\beta(1-\mu)}{1-\beta}} \\ &\times \left[\frac{1-\alpha(1-\gamma)(1-\mu)}{1-\beta(1-\mu)}\right]^{\frac{1-\beta(1-\mu)}{1-\beta}} (c_x)^{-\frac{\beta}{1-\beta}} \end{aligned}$$

- 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 μ 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 α. 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 μ_1 and $\mu_0 < \mu_1$,

$$\frac{\tilde{P}(\mu_1)}{\tilde{P}(\mu_0)} = \frac{\left[\frac{1-\alpha(1-\gamma)(1-\mu_1)}{1-\beta(1-\mu_1)}\right]^{\frac{\kappa(1-\beta(1-\mu_1))}{1-\beta(\kappa+1)}}}{\left[\frac{1-\alpha(1-\gamma)(1-\mu_0)}{1-\beta(1-\mu_0)}\right]^{\frac{\kappa(1-\beta(1-\mu_0))}{1-\beta(\kappa+1)}}} \left[\beta^{-1}\alpha(1-\gamma)\right]^{\frac{\kappa\beta(\mu_0-\mu_1)}{1-\beta(\kappa+1)}}, \tag{16}$$

- Parameter β related to substitutability of final goods and to markups. Both types of evidence suggest a β around 0.75.
- We choose κ 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 $\kappa \simeq 0.25$.

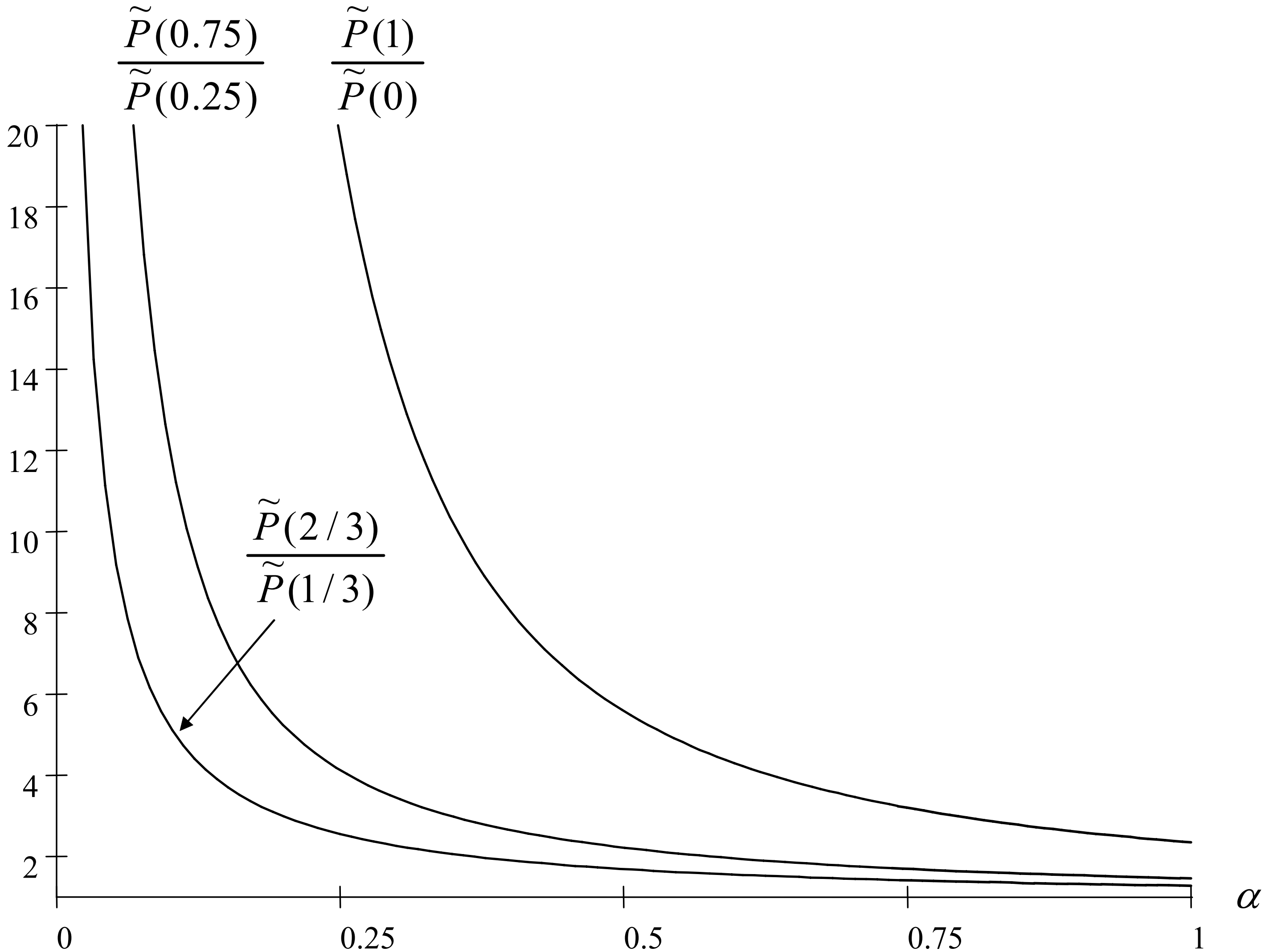

Figure 1: Relative productivity for $\beta = 0.75$ and $\kappa = 0.25$

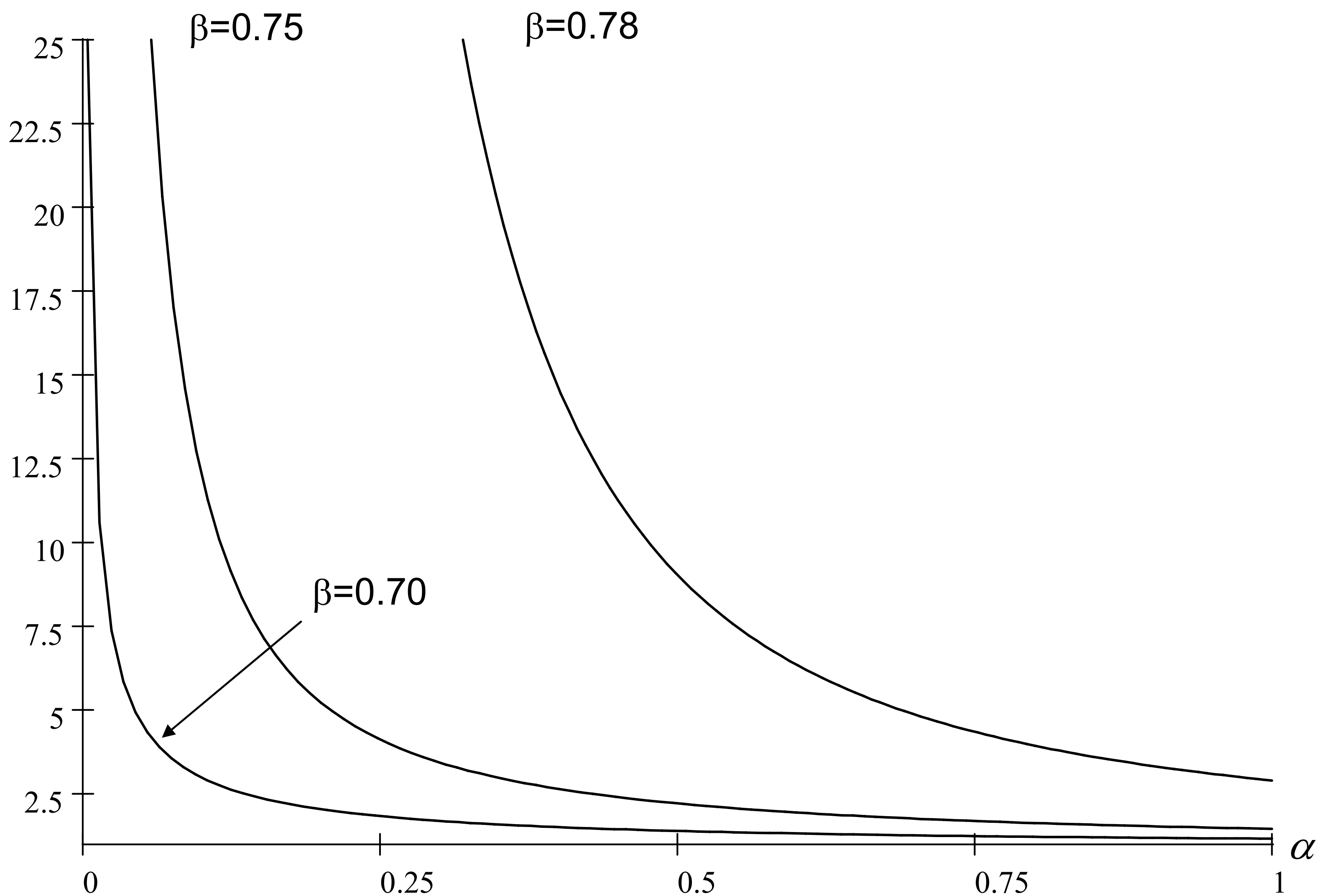

Figure 2: Relative productivity $\tilde{P}\,(0.75)\,/\tilde{P}\,(0.25)$ for $\kappa = 0.25$ and alternative β's.

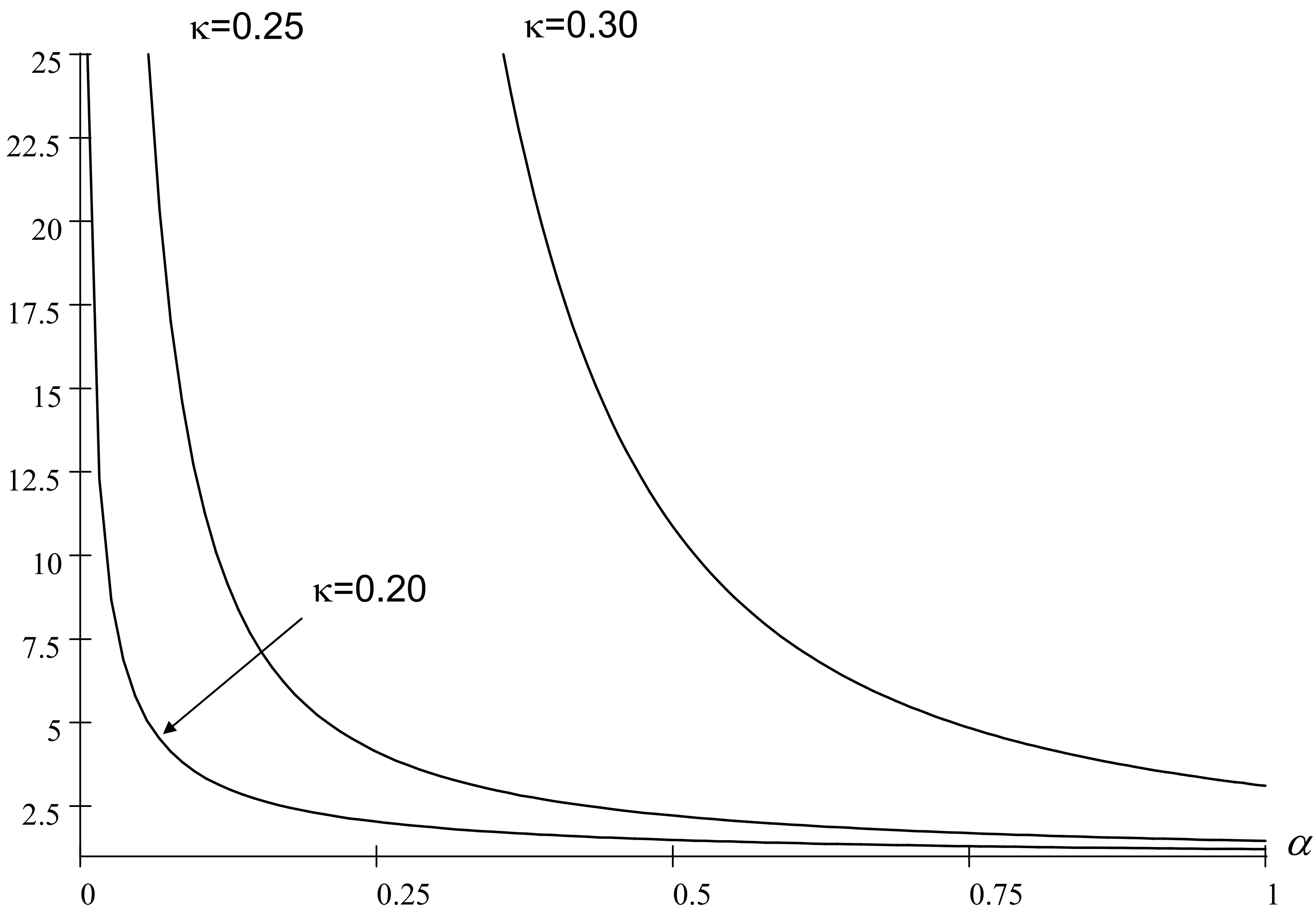

Figure 3: Relative productivity $\tilde{P}\,(0.75)\,/\tilde{P}\,(0.25)$ for $\beta = 0.75$ and alternative κ's.

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 α'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.