Technology Transfer in Global Value Chains

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Global value chains & technology

- Global value chains may enable countries to short-circuit the development process by obtaining foreign technologies through cross-border firm-to-firm relationships (Baldwin 2016)
- Empirical literature documents productivity-enhancing transfers of technology and other intangibles between producers and suppliers (Javorcik 2004, Alfaro-Ureña, Manelici & Vasquez 2019)
- New technologies may diffuse beyond value chains to the broader economy

This paper

- Develop theory of technology transfer when input production technologies are
  - Non-contractible (Antràs 2003)
  - Non-rival & imperfectly excludable
- Partial excludability means supplier's input production technology may be imitated. Study effect of imitation risk on
  - Technology transfer, efficiency and profitability within value chains
  - Wages, welfare and international inequality in general equilibrium offshoring model
- Supplier imitation conceptually distinct from product imitation analyzed in product cycle literature (Grossman & Helpman 1991)

Inclusive & exclusive value chains

- Imitation risk affects headquarters' profits through three channels
  - Additional supplier strengthens headquarters firm's bargaining position
  - Imitation prevents headquarters from appropriating entire value chain surplus
  - Imitation risk affects incentives to invest in technology transfer
- Classify two types of value chains
  1. *Inclusive value chains:* headquarters firm benefits from supplier imitation $\Rightarrow$ sharing incentive
  2. *Exclusive value chains:* headquarters firm loses from supplier imitation $\Rightarrow$ secrecy incentive

Offshoring & development

- Embed technology transfer theory in North-South offshoring model to study value chains in general equilibrium
- Comparative statics differ qualitatively in inclusive vs exclusive value chains
- Consider technical change or weakening of intellectual property rights that reduces cost of supplier imitation in South
  - Inclusive value chains: wages rise in both countries and international inequality falls
  - Exclusive value chains: wages fall in both countries and international inequality rises
- Bias of technical change matters, e.g. lower international technology transfer cost raises wages in both countries and reduces international inequality regardless of value chain type
- With knowledge spillovers beyond supply chains, sharing incentive in inclusive value chains is socially efficient. Secrecy incentive in exclusive value chains need not be

Technology transfer model

- Headquarters firm owns product blueprint, but needs to hire input supplier to produce
- Large number of potential suppliers with zero outside option
- Supplier makes ex-ante transfer to headquarters to satisfy participation constraint
- Supplier must learn to produce relationship-specific input. Learning requires headquarters h and supplier m to invest in technology transfer
- Technology investments z_h and z_m give supplier productivity

$$z = z_h^{\gamma} z_m^{1-\gamma}$$

  $\gamma \in [0, 1]$ determines relative importance of headquarters vs supplier technology transfer investments
- Investment costs $f_i w_i z_i^{\delta}$ for $i = h, m$, where f_i technology transfer cost parameter, w_i wage, δ elasticity of technology transfer costs

Production

- Labor only factor of production
- Supplier produces input quantity $y_m = zl_m$
- Headquarters transforms inputs one-to-one into final output at zero cost
- Inputs are relationship-specific and have no value outside of relationship
- Input production & technology transfer investments are non-contractible
- Headquarters faces constant elasticity demand $y = Ap^{-\sigma}$, where $\sigma - 1 < \delta$

Imitation

- Imitator copies supplier's input technology with exogenous probability q
- Imitation occurs after technology investments are sunk, but before production
- Successful imitator has same productivity z as supplier & produces same homogeneous input
- Imitator g produces inputs $y_g = zl_g$
- Headquarters may purchase input from both supplier and imitator
- Sales revenue divided between headquarters, supplier and imitator (if one exists) according to Shapley value

Stages of production

Hire input supplier	Technology transfer	Imitation	Input production	Production & revenue sharing
1	2	3	4	5

- Hold-up problems due to non-contractible relationship-specific investments occur at stage 2 & stage 4
- Solve for subgame perfect Nash equilibrium using backward induction
- Complete contracts equilibrium is independent of imitation probability q. Input contractibility sufficient to achieve complete contracts equilibrium even if technology investments non-contractible

Stages 4 & 5

- Stage 5: revenue sharing Details
  - Competition between supplier & imitator allows headquarters to capture greater share of revenue
  - Imitator appropriates part of the production surplus

Stages 4 & 5

- Stage 5: revenue sharing Details
  - Competition between supplier & imitator allows headquarters to capture greater share of revenue
  - Imitator appropriates part of the production surplus
- Stage 4: input production Details
  - Supplier & imitator choose input levels to maximize Shapley value net of production costs
  - Imitation alleviates stage 4 hold-up inefficiency

$$\tilde{y}_m < y_m < \tilde{y}_m + \tilde{y}_g < y^c$$

$\tilde{y}_i$ for $i = m, g$ denotes input production if imitation occurs, y^c is complete contracts production

  - Imitation increases headquarters' payoff from stage 4 onwards, decreases supplier's payoff. Effect on combined payoff positive for large σ

Stage 2: technology transfer

- Headquarters & supplier make independent technology transfer investments taking probability of imitation as given
- Imitation risk affects technology transfer by changing expected payoffs at stage 4

Lemma

There exists $0 < \gamma_1^* < \gamma_2^* < 1$ *such that:*
(i) If $\gamma < \gamma_1 *$ *higher imitation risk reduces supplier productivity z*
(ii) If $\gamma > \gamma_2 *$ *higher imitation risk increases supplier productivity z*
(iii) If $\gamma_1^* < \gamma < \gamma_2^*$ *then supplier productivity is inverse-U shaped in imitation risk*

Stage 2

Headquarters' profits

- Expected profits given by production surplus less imitator's payoff

$$\pi_h = \frac{\hat{\alpha}_h \left[\delta - \gamma(\sigma - 1)\right] + \hat{\alpha}_m \left[\delta - (1-\gamma)(\sigma - 1)\right]}{\sigma - 1}$$
$$\times \left[\left(\frac{\sigma - 1}{\sigma} \right)^{\sigma} \frac{1}{\delta} \frac{A}{w_m^{\sigma-1}} \left(\frac{\gamma \hat{\alpha}_h}{f_h w_h} \right)^{\frac{\gamma(\sigma-1)}{\delta}} \left(\frac{(1-\gamma)\hat{\alpha}_m}{f_m w_m} \right)^{\frac{(1-\gamma)(\sigma-1)}{\delta}} \right]^{\frac{\delta}{\delta+1-\sigma}}$$

- Imitation risk affects π_h through expected payoff coefficients $\hat{\alpha}_i$ for $i = h, m$ with $\hat{\alpha}_h'(q) > 0$, $\hat{\alpha}_m'(q) < 0$

Definition

A value chain is:
(i) Inclusive if π_h is strictly increasing in q for all $q \in [0, 1]$;
(ii) Exclusive if π_h is strictly decreasing in q for all $q \in [0, 1]$.

Classifying value chains

- Imitation risk q affects profits π_h through three channels
  1. Negative: larger expected payoff to imitator
  2. Positive: alleviates hold-up inefficiency in input production
  3. Ambiguous: effect on supplier productivity z

Classifying value chains

- Imitation risk q affects profits π_h through three channels
  1. Negative: larger expected payoff to imitator
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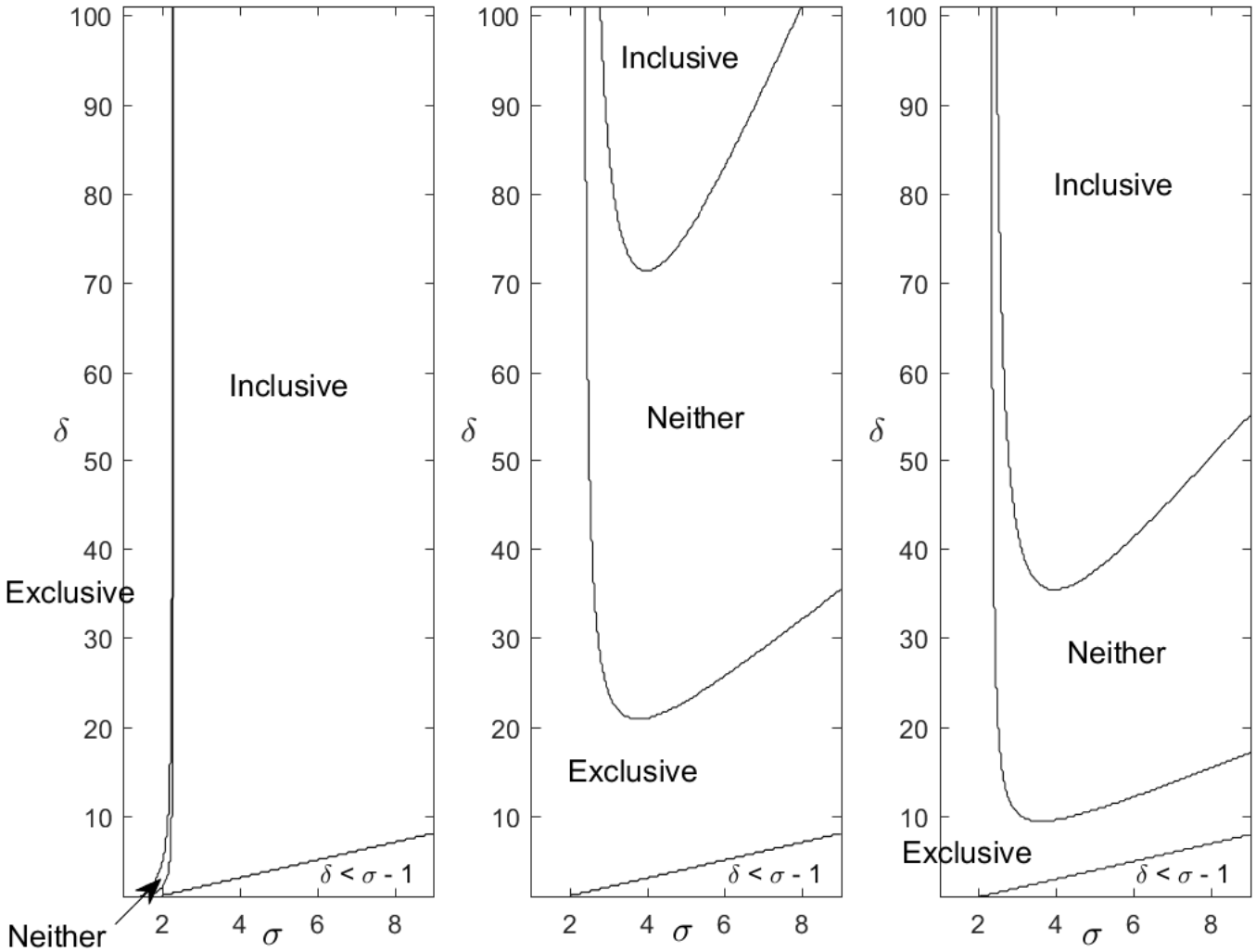
  3. Ambiguous: effect on supplier productivity z
- Value chain type determined by three parameters
  - Demand elasticity σ
  - Technology transfer cost elasticity δ
  - Knowledge transfer share γ

Classifying value chains



Intellectual property rights

- Inclusive value chains
  - Headquarters has *sharing* incentive to encourage imitation if possible
  - Headquarters will not enforce any intellectual property rights over input production technology
- Exclusive value chains
  - Headquarters has *secrecy* incentive to limit imitation
  - Ex-ante headquarters benefits from patenting input technology
  - But if imitation occurs, headquarters has incentive not to enforce patent since headquarters payoff from stage 4 onwards higher under imitation
  - Introduces role for commitment device to resolve time-inconsistency, e.g. transfer patent rights to supplier
- Intellectual property rights are not only avenue to affect excludability of input technology, e.g. integration vs outsourcing

Offshoring model

- Two countries: North N and South S
- Consumption good produced competitively as constant elasticity σ aggregate of headquarters' differentiated varieties
- Inputs and differentiated output freely tradable
- Consumption good numeraire, deamand parameter A equals global consumption expenditure E
- Populations L^N, L^S
- Homogeneous labor implying wages country specific $w_h^j = w_m^j = w_g^j = w^j$

Innovation

- Innovate to create product blueprints. Innovation requires a^j units of labor per blueprint
- Assume a^S sufficiently large that South does not innovate
- Free entry into innovation at stage zero
- Successful innovators may hire domestic supplier or offshore input production to South. Assume North sufficiently large that headquarters firms hire suppliers in both countries
- Domestic technology transfer costs $f_h = f_m = f^N$
- International technology transfer costs $f_h = \lambda f^N$, $f_m = \lambda f^S$ where $\lambda > 1$ is technology offshoring cost

Imitation

- Free entry into imitation at stage three in both North and South
- All imitation occurs within countries, i.e. international spillovers weaker than domestic spillovers (Jaffe, Trajtenberg & Henderson 1993, Branstetter 2001, Keller 2002)
- Imitation cost $b^j \mu\left(\frac{M_g^j}{M_m^j}\right)$ labor units where M_m^j denotes mass of input suppliers, M_g^j mass of imitators
- $\mu(\cdot)$ strictly increasing bijection from $[0,1)$ to $[0,\infty)$. Implies imitation cost rises as ratio of imitators to imitation targets increases
- Each imitator randomly matched with supplier. Equilibrium imitation risk

$$q^j = \frac{M_g^j}{M_m^j}$$

- Characterize equilibrium conditional on value chain type

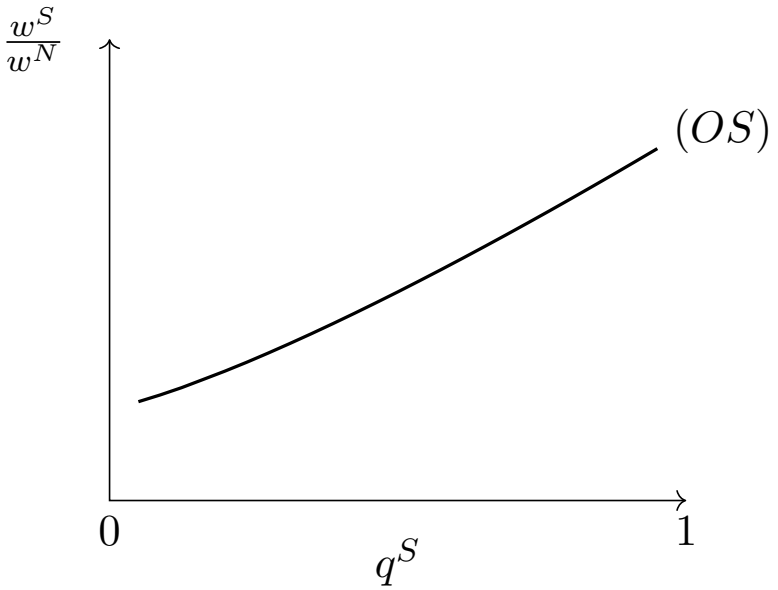
Offshoring equilibrium

Proposition

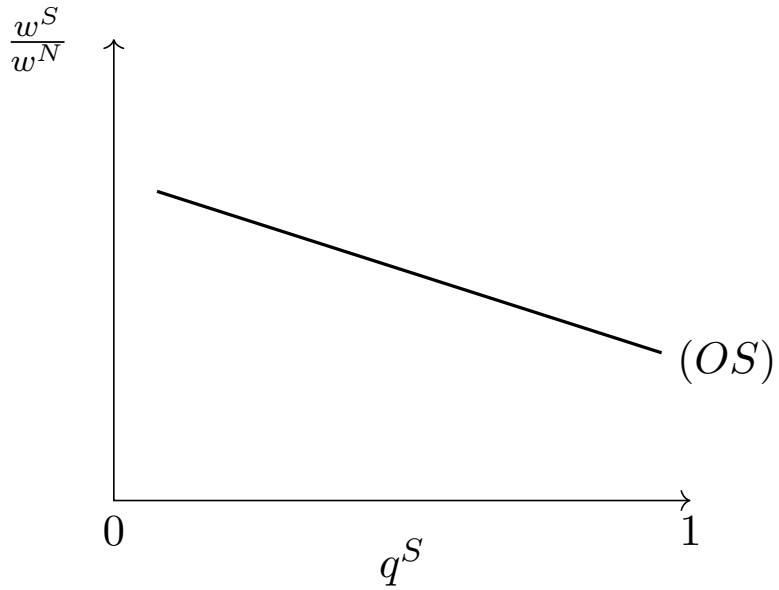
Under appropriate regularity conditions*, the offshoring model has a unique equilibrium*

- Free entry implies expected net profits of innovators & imitators are zero
- Changes in imitation risk affect equilibrium wages
- Partial equilibrium: higher imitation risk raises wage in inclusive value chains, decreases wage in exclusive value chains
- General equilibrium: correlation between imitation risk and wage depends upon type of shock

Offshoring indifference condition

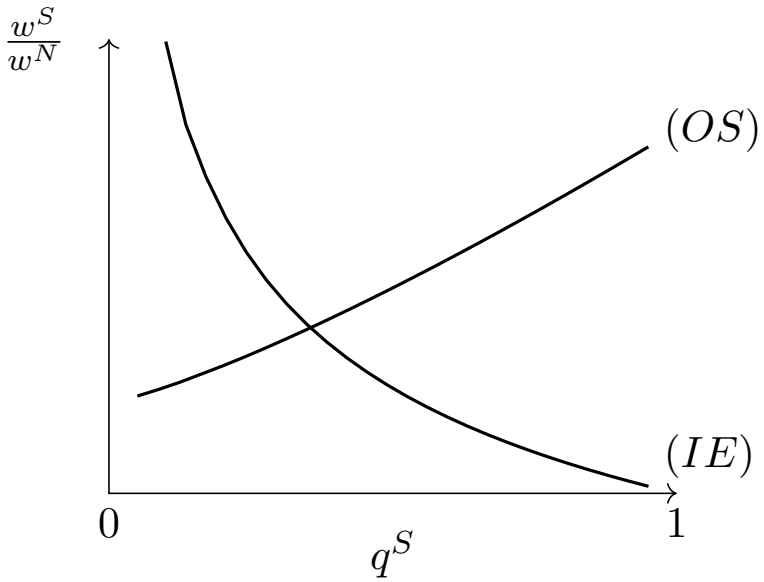


(a) Inclusive value chains



(b) Exclusive value chains

Equilibrium



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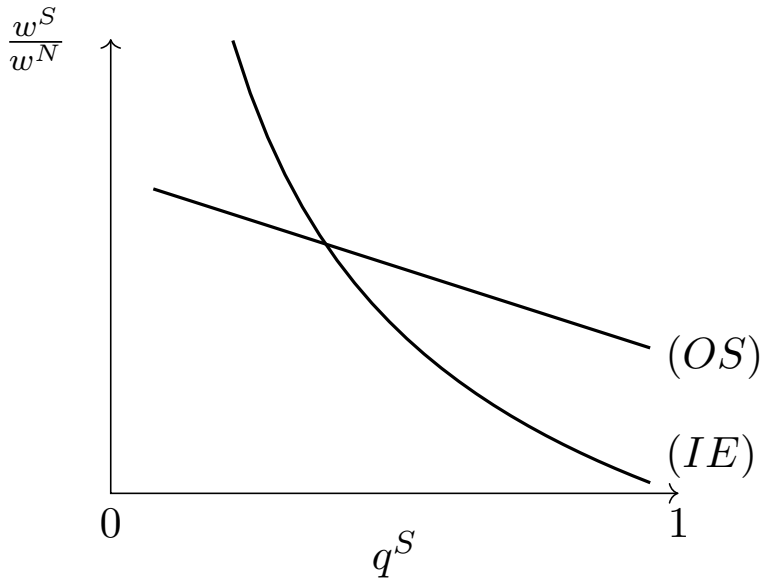
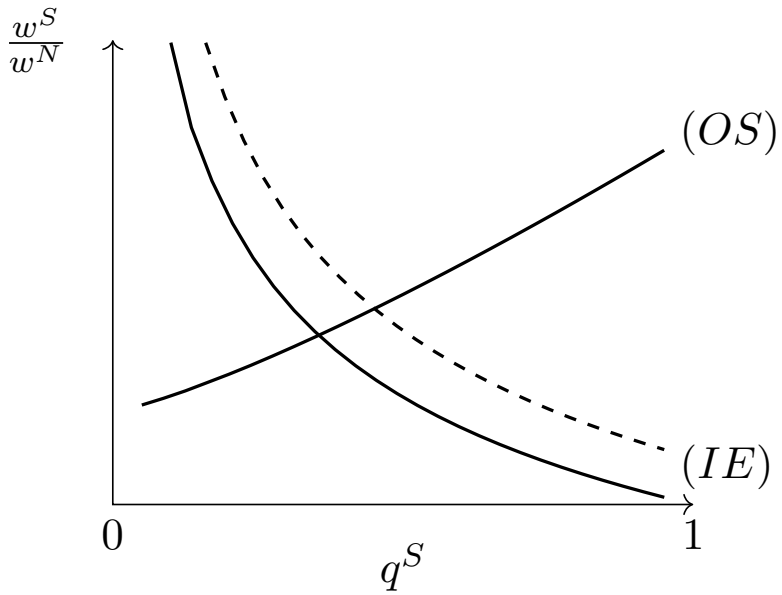
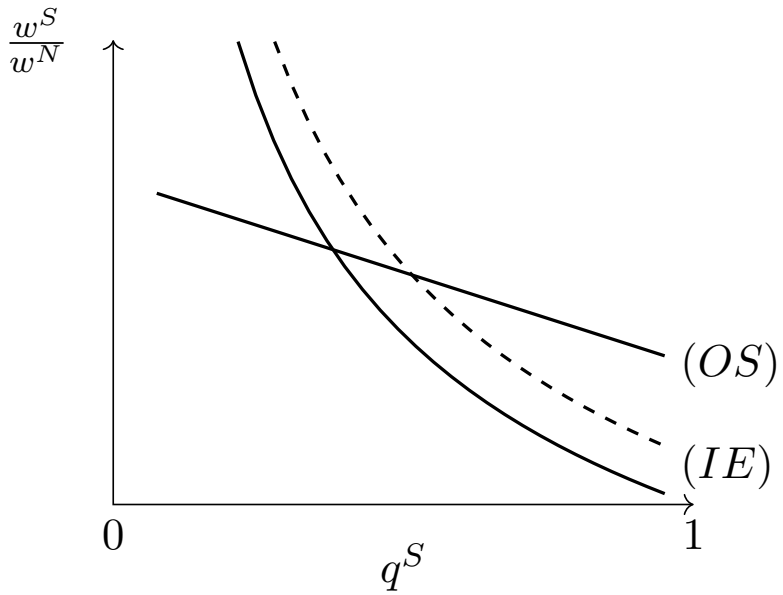


(b) Exclusive value chains

Decline in Southern imitation cost b^S



(a) Inclusive value chains



(b) Exclusive value chains

Decline in Southern imitation cost b^S

Proposition

A decline in the Southern imitation cost b^S increases imitation risk in the South, does not affect imitation risk in the North and:
(a) when supply chains are inclusive, increases real wages in both countries and the relative wage in the South;
(b) when supply chains are exclusive, decreases real wages in both countries and the relative wage in the South

- Decline in b^S could result from lower excludability in South or improvement in capability of Southern imitators
- Optimal intellectual property policy depends upon value chain type

Bias of technical change

- Not all shocks have qualitatively different effects in inclusive vs exclusive value chains. Type of technical change matters
- Decline in international technology transfer cost λ reduces imitation risk in South, but raises relative wage in South and increases real wage in both countries regardless of value chain type
- Balanced global technical change raises wage in both countries, but does not affect relative wage levels or imitation risk

Model applications

- Supply chain choice
  - Suppose headquarters can establish an inclusive or an exclusive value chain
  - Choose to set-up inclusive value chains in low imitation cost countries, but exclusive value chains in high imitation cost countries
  - Relative wage w^S/w^N U-shaped function of imitation costs b^S
- Knowledge spillovers & social efficiency
  - Suppose innovators choose open or secret research, where open research lowers imitation costs
  - In baseline model social preferences over imitation costs are aligned with private preferences of innovators
  - With knowledge spillovers, secrecy incentive in exclusive value chains may be socially inefficient

Conclusions

- Develop incomplete contracts model of technology transfer and supplier imitation in global value chains
- Identify two types of value chain
  1. Inclusive: imitation benefits headquarters, sharing incentive
  2. Exclusive: imitation reduces headquarters' profits, secrecy incentive
- In offshoring model, impact of technology and institutional shocks depend upon bias of technical change and whether value chains are inclusive or exclusive
- Improvements in imitation capacity or weaker intellectual property rights raise wages and reduce international inequality when value chains are inclusive. Opposite effects under exclusive value chains

Stage 5: revenue sharing

- Let V_i be Shapley value of player $i = h, m$ without imitation

$$V_h = V_m = \frac{1}{2} A^{\frac{1}{\sigma}} y_m^{\frac{\sigma-1}{\sigma}}.$$

- Let $\tilde{V}_i$ be Shapley value of player $i = h, m, g$ with imitation

$$\tilde{V}_h = \frac{A^{\frac{1}{\sigma}}}{6}\left[2\left(\tilde{y}_m + \tilde{y}_g\right)^{\frac{\sigma-1}{\sigma}} + \tilde{y}_m^{\frac{\sigma-1}{\sigma}} + \tilde{y}_g^{\frac{\sigma-1}{\sigma}}\right],$$

$$\tilde{V}_m = \frac{A^{\frac{1}{\sigma}}}{6}\left[2\left(\tilde{y}_m + \tilde{y}_g\right)^{\frac{\sigma-1}{\sigma}} + \tilde{y}_m^{\frac{\sigma-1}{\sigma}} - 2\tilde{y}_g^{\frac{\sigma-1}{\sigma}}\right],$$

$$\tilde{V}_g = \frac{A^{\frac{1}{\sigma}}}{6}\left[2\left(\tilde{y}_m + \tilde{y}_g\right)^{\frac{\sigma-1}{\sigma}} - 2\tilde{y}_m^{\frac{\sigma-1}{\sigma}} + \tilde{y}_g^{\frac{\sigma-1}{\sigma}}\right].$$

- Stage 5 payoffs are conditional on input production levels

Back

Stage 4: input production

- Let V_i^* denote payoff from stage 4 onwards without imitation, $\tilde{V}_i^*$ with imitation

$$\tilde{V}_i^* = \frac{\tilde{\alpha}_i}{\sigma}\left(\frac{\sigma-1}{\sigma}\right)^{\sigma-1} A\left(\frac{z}{w_m}\right)^{\sigma-1}, \qquad i = h, m, g,$$

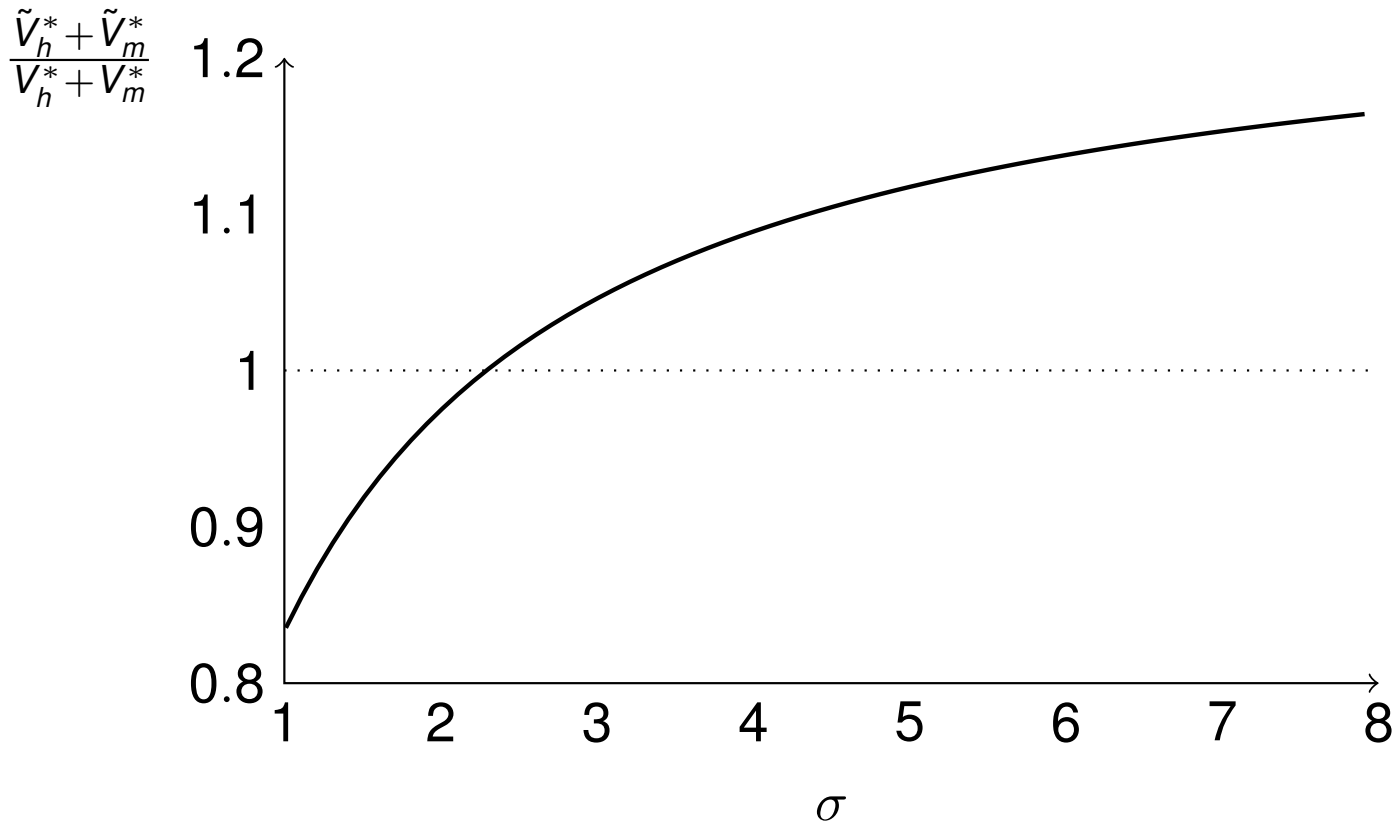
$$V_i^* = \frac{\alpha_i}{\sigma}\left(\frac{\sigma-1}{\sigma}\right)^{\sigma-1} A\left(\frac{z}{w_m}\right)^{\sigma-1}, \qquad i = h, m,$$

where $1 > \tilde{\alpha}_h > \alpha_h > \alpha_m > \tilde{\alpha}_m = \tilde{\alpha}_g$

$$\tilde{\alpha}_h = \sigma\left(\frac{1+2^{-\frac{\sigma-1}{\sigma}}}{3}\right)^{\sigma}, \ \alpha_h = \frac{\sigma}{2^\sigma}, \ \alpha_m = \frac{1}{2^\sigma},$$

$$\tilde{\alpha}_m = \tilde{\alpha}_g = \frac{1}{6^\sigma}\left(1+2^{\frac{\sigma-1}{\sigma}}\right)^{\sigma-1}\left[1+2^{\frac{\sigma-1}{\sigma}} - \sigma\left(2-2^{\frac{\sigma-1}{\sigma}}\right)\right].$$

Stage 4: input production



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Stage 2: technology transfer

- Player $i = h, m$ chooses z_i to maximize

$$\hat{V}_i = (1-q)V_i^* + q\tilde{V}_i^* - f_i w_i z_i^{\delta}$$

- Define expected stage 4 payoff coefficients as

$$\hat{\alpha}_i = (1-q)\alpha_i + q\tilde{\alpha}_i = \alpha_i + q\left(\tilde{\alpha}_i - \alpha_i\right)$$

- Supplier's equilibrium productivity is

$$z = \left[\left(\frac{\sigma-1}{\sigma}\right)^{\sigma}\frac{1}{\delta}\frac{A}{w_m^{\sigma-1}}\left(\frac{\gamma\hat{\alpha}_h}{f_h w_h}\right)^{\gamma}\left(\frac{(1-\gamma)\hat{\alpha}_m}{f_m w_m}\right)^{1-\gamma}\right]^{\frac{1}{\delta+1-\sigma}}$$

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Regularity assumptions

For all $q \in [0,1)$

Assumption

$$\chi_1 \equiv \frac{(\tilde{\alpha}_h - \alpha_h)[\delta - \gamma(\sigma-1)] + (\tilde{\alpha}_m - \alpha_m)[\delta - (1-\gamma)(\sigma-1)]}{\hat{\alpha}_h[\delta - \gamma(\sigma-1)] + \hat{\alpha}_m[\delta - (1-\gamma)(\sigma-1)]} + \frac{\mu'(q)}{\mu(q)} > 0.$$

Assumption

$$\chi_2 \equiv \frac{(\tilde{\alpha}_h - \alpha_h)[\delta - \gamma(\sigma-1)] + (\tilde{\alpha}_m - \alpha_m)[\delta - (1-\gamma)(\sigma-1)]}{\hat{\alpha}_h[\delta - \gamma(\sigma-1)] + \hat{\alpha}_m[\delta - (1-\gamma)(\sigma-1)]}$$
$$+ \frac{\sigma - 1}{\delta\sigma - \gamma(\sigma-1)}\left[\frac{\gamma(\tilde{\alpha}_h - \alpha_h)}{\hat{\alpha}_h} + \frac{(1-\gamma)(\tilde{\alpha}_m - \alpha_m)}{\hat{\alpha}_m} + (\delta + 1 - \gamma)\frac{\mu'(q)}{\mu(q)}\right] > 0.$$

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