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Optimal R&D Subsidies, Industry Location, and Productivity Growth

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Motivation

- Record world expenditure on R&D in 2020: 2.63% of world GDP.
- Expanding R&D spending driven by a large range of countries: OECD average increased from 1.51% to 2.16% of GDP between 2000 and 2019. Many OECD members have spending of over 3%.
- Public support for private R&D expenditure is also on the rise in the form of grants and tax incentives.
- Governments increasingly recognize the international nature of private R&D spending and design policy with the aim of attracting R&D-related FDI (Guimon 2011; Rodriguez-Pose and Wilkie 2016; Guimon et al. 2017).

Motivation

- To develop a two-country model of fully endogenous productivity growth and occupational choice in which footloose manufacturing and innovation do not necessarily lead to the full concentration of research development (R&D) in one country.

- Use this model to study how changes in

→ trade costs
→ international knowledge diffusion
→ R&D subsidies

affect R&D locations patterns and to consider the implications for market entry, productivity growth and national welfare.

- We are also interested in investigating how market integration affects optimal R&D subsidies. Work is ongoing.

Related Literature

- A large number of papers examine the relationship between innovation-based growth and manufacturing location patterns (Martin and Ottaviano 1999; Gao 2007; Naghavi and Ottaviano 2009, 2010).

- Ekholm and Hakkala (2007) develop a general-equilibrium model of trade in which firms locate production and R&D independently.

- A small literature considers the relationship between innovation-based growth and R&D location patterns (Davis 2013, Davis and Hashimoto 2023).

Related Literature

- Impullitti (2010) concludes that increased foreign competition leads to a rise in the optimal R&D subsidy for the United States.

- Kondo (2013) develops an economic geography model of endogenous growth in which industry agglomerates in a single country, and shows that R&D subsidy competition becomes less intense as trade costs fall.

- Milicevic et al. (2022) find that there are substantial gains to innovation policy coordination in the form of harmonized R&D subsidies in the EU.

Model Framework

Firm-level investment in process innovation that increases labor productivity in production is the driver of economic growth.

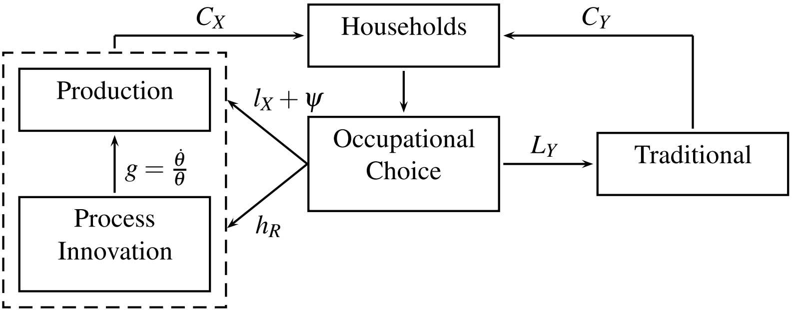
- The endogenous occupational choice of heterogenous workers into low-skilled employment in production and high-skilled employment in innovation determines national labor allocations.
- Free capital movement between countries enables manufacturing firms to shift their production and innovation activities independently between countries with the aim of minimizing costs.
- A tension between access to local knowledge spillovers from production to innovation and high-skilled labor costs determines the equilibrium location pattern for firm-level R&D.

Model Framework

Two-country model of trade and endogenous productivity growth.

- → Countries differ with respect to market (population) size
- → Occupational choice: low-skilled (L) or high-skilled (H)
- → Monopolistically competitive firms produce for domestic and export markets and invest in process innovation
- → Production and process innovation are located independently with the aim of minimizing costs
- → There are iceberg trade costs and incomplete knowledge spillovers between countries

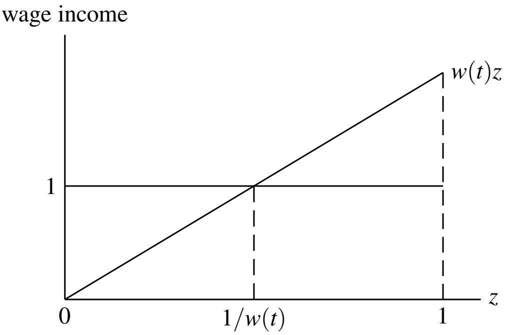
The economy of the home country:



- Low-skilled labor is employed in production.
- High-skilled labor is employed in process innovation.

Endogenous Labor Supplies

In each country, workers choose the employment type that offers the highest wage income: $\max[1, zw(t)]$.



▶ With active production and innovation sectors, there exists a marginal worker with skill level $z = 1/w(t)$.

Households

- Lifetime utility:

$$U = \int_0^{\infty} e^{-\rho t} \left[\alpha \ln C_X(t) + C_Y(t) \right] dt.$$

- Flow budget constraint:

$$\dot{A}(t) = r(t)A(t) + L(t) + w(t)H(t) - E(t) - T(t).$$

- The composite price index for manufacturing goods is

$$P_X(t) = \left(\int_0^{n(t)} p_i(t)^{1-\sigma} di + \int_0^{n^*(t)} p_j^*(t)^{1-\sigma} dj \right)^{1/(1-\sigma)}$$

- Demands for a varieties produced in home and foreign:

$$q_i(t) = \alpha p_i(t)^{-\sigma} P_X(t)^{\sigma-1} P_Y(t), \quad q_j^*(t) = \alpha p_j^*(t)^{-\sigma} P_X(t)^{\sigma-1} P_Y(t).$$

Manufacturing Sector

- Monopolistically competitive firms.

→ Constant price-cost markup: $p(t) = \sigma / [(\sigma - 1)\theta(t)^{\gamma}]$

- Production technology: $x(i,t) = \theta(t)^{\gamma}(l_X(i,t) - \psi)$.

- Operating profit for a firm with home-based production is

$$\pi(t) = p(t)x(t) - l_X(t) = \frac{\alpha p(t)^{1-\sigma}}{\sigma}\left(\frac{Z}{P_X(t)^{1-\sigma}} + \frac{\varphi Z^*}{P_X(t)^{*\,1-\sigma}}\right) - \psi,$$

→ Iceberg trade costs (τ): $p^*(t) = \tau p(t)$ and $\varphi = \tau^{1-\sigma}$.

Process Innovation

- Firm-level productivity evolves according to

$$\dot{\theta}(t) = \beta k \theta(t) h_R(t)$$

$\rightarrow$ $\beta > 0$.

- The strength of knowledge spillovers is determined by

$$k = s_X + \delta(1 - s_X)$$

$\rightarrow$ the degree of knowledge diffusion $\delta \in (0,1)$ determines the strength of international knowledge spillovers.

Process Innovation

- Total per-period profit:

$$\Pi(t) = \pi(t) - (1-\Delta)w(t)h_R(t)$$

- Choose h_R to maximize firm value

$$V = \int_0^\infty \Pi(t)e^{-\rho t} \qquad \text{subject to} \qquad \dot{\theta}(t) = \beta k \theta(t) h_R(t)$$

taking labor productivity $\beta k \theta(t)$ as given.

- The no-arbitrage condition for investment in process innovation:

$$p_R(t) = \frac{(1-\Delta)w(t)}{\beta k(t)\theta(t)}, \quad p_R(t)\rho - \dot{p}_R(t) = \frac{\partial \pi(t)}{\partial \theta(t)} = \frac{\alpha\gamma(\sigma-1)(Z+Z^*)}{\sigma\theta(t)N(t)}$$

Equilibrium Production Shares

- Operating profit on sales equalizes across countries: $\pi(t) = \pi^*(t)$.
- The Home country's equilibrium production shares becomes

$$s_X \equiv \frac{n(t)}{N(t)} = \frac{Z - \varphi Z^*}{(1-\varphi)(Z+Z^*)}.$$

$\rightarrow$ Home market effect: $Z > Z^* \Longrightarrow s_X > 1/2$.

Equilibrium Production Shares

- The shadow value of new process innovation also equalizes across countries: ($p_R = p_R^*$).

- The home share of manufacturing that equalizes innovation costs across countries is

$$s_X = \frac{(1-\Delta)w(t) - \delta(1-\Delta^*)w^*(t)}{(1-\delta)((1-\Delta)w(t) + (1-\Delta^*)w^*(t))}.$$

- We define the regional component of innovation costs as

$$c(t) = \frac{(1-\Delta)w(t)}{\beta k} = \frac{(1-\Delta^*)w^*(t)}{\beta k^*} = \frac{(1-\Delta)w(t) + (1-\Delta^*)w^*(t)}{\beta(1+\delta)}.$$

Long-run Equilibrium

- Long-run labor allocations are determined implicitly through two conditions ($\dot{w} = \dot{w}^* = 0$): a share locus and an investment locus.

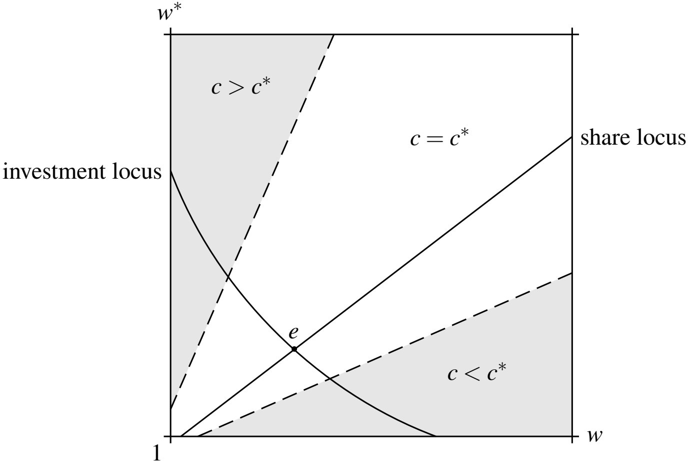
- The share locus is given by $(1-\Delta)w/k = (1-\Delta^*)w^*/k^*$:

$$\frac{w^*}{w} = \left(\frac{1-\Delta}{1-\Delta^*}\right)\left(\frac{(\delta-\varphi)Z + (1-\delta\varphi)Z^*}{(1-\delta\varphi)Z + (\delta-\varphi)Z^*}\right)$$

- The investment locus is given by

$$(1-\Delta)wH + (1-\Delta^*)w^*H^* = \frac{\alpha(\gamma(\sigma-1)\psi - \rho c)(Z+Z^*)}{\sigma(\psi-\rho c)}$$

Long-run Equilibrium ...



Equilibrium Market Entry

- The long-run level of market entry is

$$N = \frac{\alpha(1-\gamma(\sigma-1))(Z+Z^*)}{\sigma(\psi-\rho c)}.$$

$\rightarrow$ Market entry is increasing in the innovation cost (c):
$dN/dc = \rho N/(\psi - \rho c) > 0.$

- The long-run rate of productivity growth is

$$g \equiv \frac{\dot{\theta}}{\theta} = \frac{\alpha\gamma(\sigma-1)(Z+Z^*)}{\sigma c N} - \rho = \frac{\gamma(\sigma-1)\psi - \rho c}{(1-\gamma(\sigma-1))c}.$$

$\rightarrow$ Productivity growth is decreasing in the innovation cost (c):
$dg/dc = -(g+\rho)\psi/((\psi-\rho c)c) < 0.$

National Welfare

- Household welfare levels in home and foreign are

$$U(0) = B + \frac{\alpha}{\rho(\sigma-1)} \ln \frac{(1+\varphi)Z}{(Z+Z^*)} N + \frac{\alpha\gamma g}{\rho^2} + \frac{L+(1-\Delta)wH}{\rho Z}$$

$$U^*(0) = B + \frac{\alpha}{\rho(\sigma-1)} \ln \frac{(1+\varphi)Z^*}{(Z+Z^*)} N + \frac{\alpha\gamma g}{\rho^2} + \frac{L^*+(1-\Delta^*)w^*H^*}{\rho Z^*}$$

where $B = -\alpha/\rho(1-\ln(\alpha(\sigma-1)/\sigma)$ and $\theta(0) = \theta^*(0) = 1$.

- Welfare is linked with R&D location patterns through:

→ the level of market entry
→ the rate of productivity growth
→ after-tax labor income

Policy Analysis

- We use the model to study several types of economic policy:
  - → Lower trade costs
  - → Greater knowledge diffusion
  - → R&D subsidies

Trade Integration

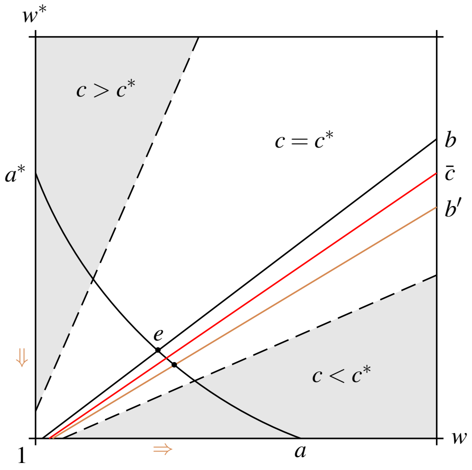
Proposition 1

A decrease in trade costs (a rise in φ) expands high-skilled employment in the larger home country and contracts high-skilled employment in the smaller foreign country.

Market entry (N) is convex and productivity growth (g) is concave in the trade cost with a minimum and a maximum occurring at $\varphi = \bar{\varphi}$, where $\bar{\varphi}$ generates $(L + wH)/w = (L^* + w^* H^*)/w^*$.

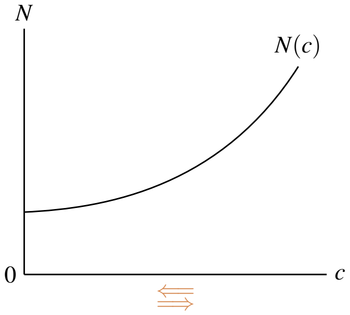
Trade Integration . . .

- An increase in φ shifts the share locus to the right.



- Innovation cost minimized at $c = \bar{c} \Longrightarrow$ where $\frac{L+wH}{w} = \frac{L^*+w^*H^*}{w^*}$.

- An increase in φ lowers the innovation cost until the minimum $\bar{c}$ is reached at $\varphi = \bar{\varphi}$, and thereafter c rises with φ.



(a) Market Entry (b) Productivity Growth

Welfare Adjustments:

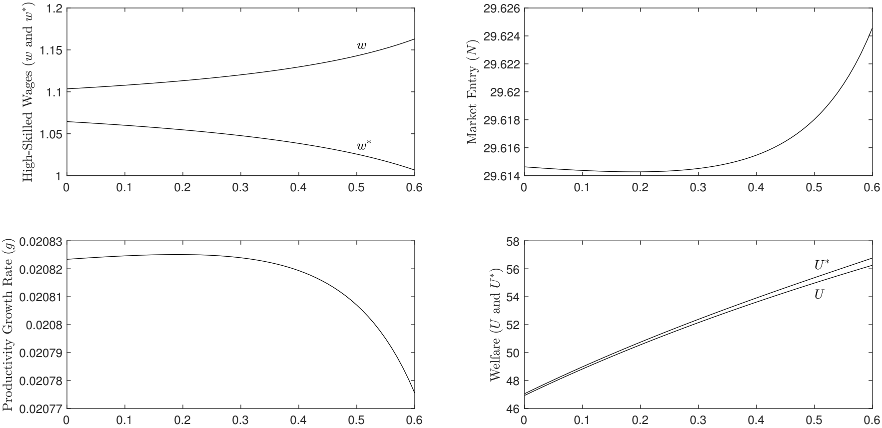
$$\frac{dU}{d\varphi} = \frac{1}{1+\varphi} - \left(\frac{1}{(\sigma-1)(\psi-\rho c)} + \frac{\gamma}{\rho c} \right) \frac{\alpha g}{\rho} \frac{dc}{d\varphi} + \frac{(1-\Delta)wH - \Delta L}{\rho Z w} \frac{dw}{d\varphi},$$

$$\frac{dU^*}{d\varphi} = \frac{1}{1+\varphi} - \left(\frac{1}{(\sigma-1)(\psi-\rho c)} + \frac{\gamma}{\rho c} \right) \frac{\alpha g}{\rho} \frac{dc}{d\varphi} + \frac{(1-\Delta^*)w^* H^* - \Delta^* L^*}{\rho Z^* w^*} \frac{dw^*}{d\varphi}.$$

→ The benefit of lower prices on imported product varieties.

→ The productivity growth channel always dominates the market entry channel: positive when innovation costs fall ($dc/d\varphi < 0$) and negative when innovation costs rise ($dc/d\varphi > 0$).

→ The adjustment in after-tax labor income may be positive or negative depending on the size of the R&D subsidy.



These figures are produced using the following parameter set: $\alpha = 1.2$ $\beta = 0.7$, $\delta = 0.15$, $\gamma = 0.15$, $\varphi = 0.2$, $\psi = 0.16$, $\rho = 0.02$, $\sigma = 4$, $Z = 10.5$, $Z^* = 10$, $\Delta = 0.15$, and $\Delta^* = 0.15$. The parameter set yields $w = 1.11$, $w^* = 1.06$, $s_X = 0.52$, $c = 2.29$, $N = 29.61$, $g = 0.021$, $U = 50.56$, and $U^* = 50.75$.

Improved Knowledge Diffusion

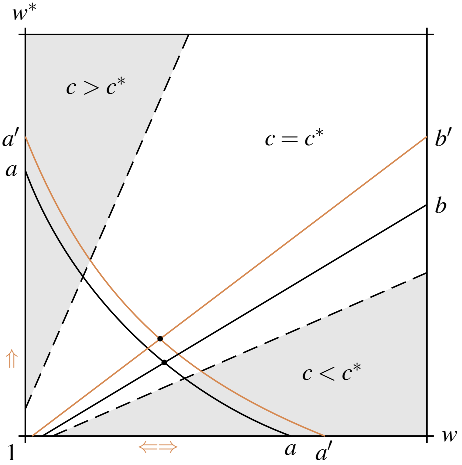
Proposition 2

An increase in the degree of knowledge diffusion (δ) expands high-skilled employment in the smaller foreign country, but has an ambiguous effect on high-skilled employment in the larger home country.

The level of market entry falls ($\partial N/\partial \delta < 0$), and the rate of productivity growth rises ($\partial g/\partial \delta > 0$).

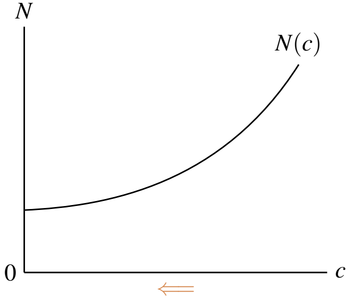
Improved Knowledge Diffusion . . .

- With an increase in δ, the share locus shifts to the left and the investment locus shifts to the right.

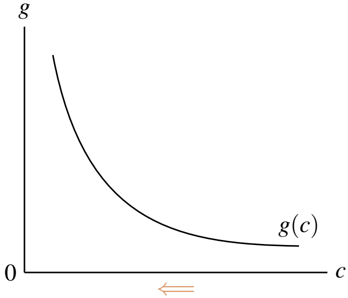


Improved Knowledge Diffusion . . .

- An increase in δ lowers the innovation cost (c) causing the level of market entry (N) to fall and the rate of productivity growth to rise (g).



(a) Market Entry



(b) Productivity Growth

Improved Knowledge Diffusion . . .

Welfare Adjustments:

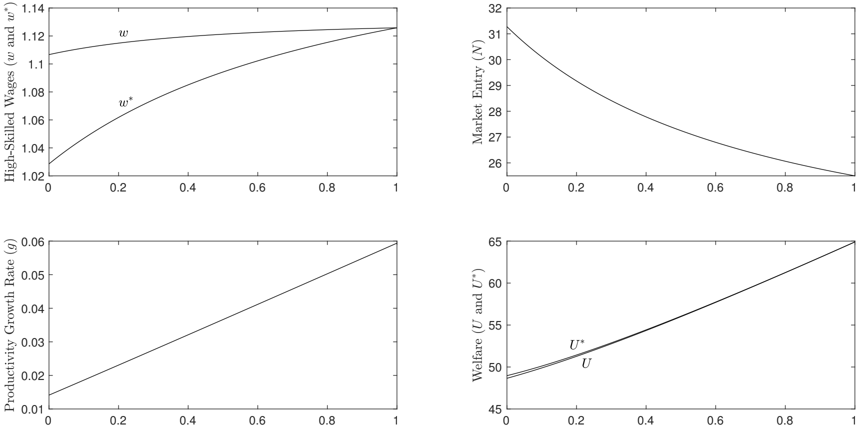
$$\frac{dU}{d\delta} = -\left(\frac{1}{(\sigma-1)(\psi-\rho c)} + \frac{\gamma}{\rho c}\right)\frac{\alpha g}{\rho}\frac{dc}{d\delta} + \frac{(1-\Delta)wH - \Delta L}{\rho Z w}\frac{dw}{d\delta},$$

$$\frac{dU^*}{d\delta} = -\left(\frac{1}{(\sigma-1)(\psi-\rho c)} + \frac{\gamma}{\rho c}\right)\frac{\alpha g}{\rho}\frac{dc}{d\delta} + \frac{(1-\Delta^*)w^*H^* - \Delta^* L^*}{\rho Z^* w^*}\frac{dw^*}{d\delta}.$$

$\rightarrow$ The productivity growth channel always dominates the market entry channel: positive because $dc/d\delta < 0$.

$\rightarrow$ The adjustment in after-tax labor income may be positive or negative depending on the size of the R&D subsidy.

Changes in the Degree of Knowledge Diffusion



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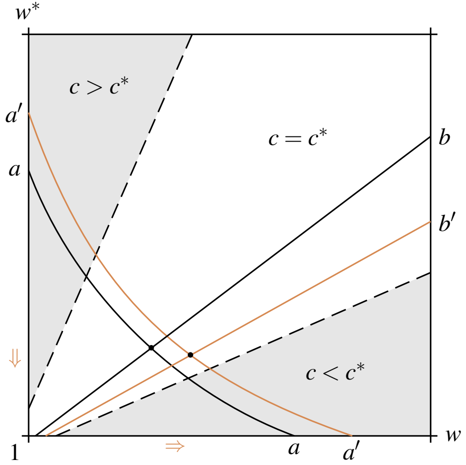
Proposition 3

An increase in the R&D subsidy rate expands high-skilled employment in the implementing country, while contracting high-skilled employment in the remaining country.

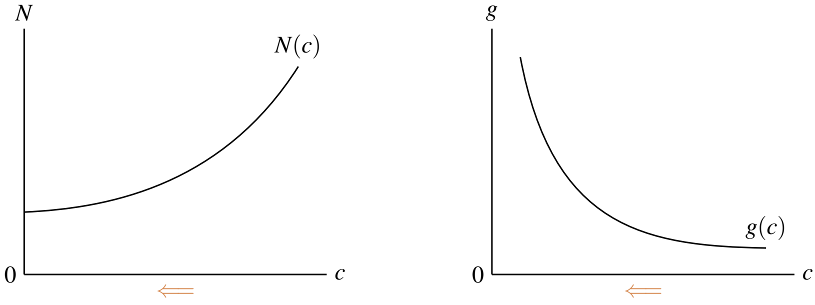
The level of market entry falls ($dN/d\Delta < 0$ and $dN/d\Delta^* < 0$), and the rate of productivity growth rises ($dg/d\Delta > 0$ and $dg/d\Delta^* > 0$).

Changes in the Home R&D Subsidy ...

- An increase in Δ shifts the share locus to the left and the investment locus upwards.



- An increase in Δ lowers the innovation cost (c) causing the level of market entry (N) to fall and the rate of productivity growth to rise (g).



(a) Market Entry (b) Productivity Growth

Welfare Adjustments:

$$\frac{dU}{d\Delta} = -\left(\frac{1}{(\sigma-1)(\psi-\rho c)} + \frac{\gamma}{\rho c}\right)\frac{\alpha g}{\rho}\frac{dc}{d\Delta} + \frac{(1-\Delta)wH - \Delta L}{\rho Z c}\frac{dc}{d\Delta} - \frac{\Delta L}{(1-\Delta)\rho Z},$$

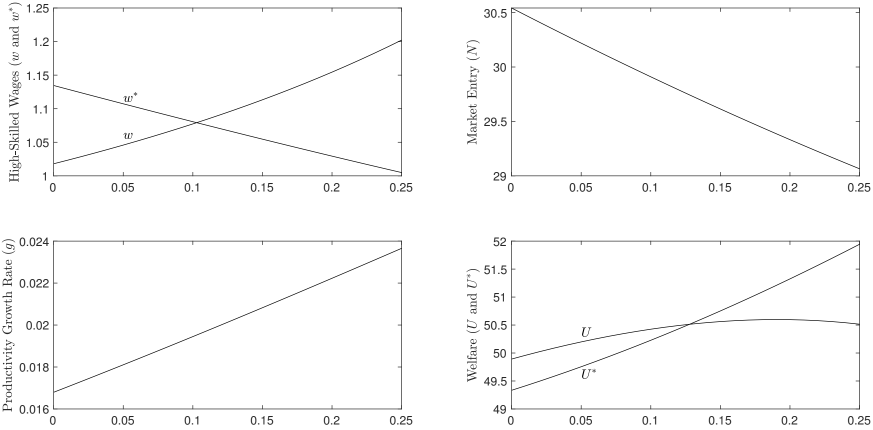
$$\frac{dU^*}{d\Delta} = -\left(\frac{1}{(\sigma-1)(\psi-\rho c)} + \frac{\gamma}{\rho c}\right)\frac{\alpha g}{\rho}\frac{dc}{d\Delta} + \frac{(1-\Delta^*)w^*H^* - \Delta^* L^*}{\rho Z^* c}\frac{dc}{d\Delta}.$$

→ The productivity growth channel always dominates the market entry channel: positive because $dc/d\Delta < 0$.

→ The adjustment in after-tax labor income may be positive or negative depending on the size of the R&D subsidy.

→ The direct negative effect of taxing home households to finance the increase in the R&D subsidy.

Changes in the Home R&D Subsidy



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Optimal R&D Subsidies

- Ideally, we would like to study how optimal R&D subsidies adjust to changes in trade costs and the degree of knowledge diffusion.

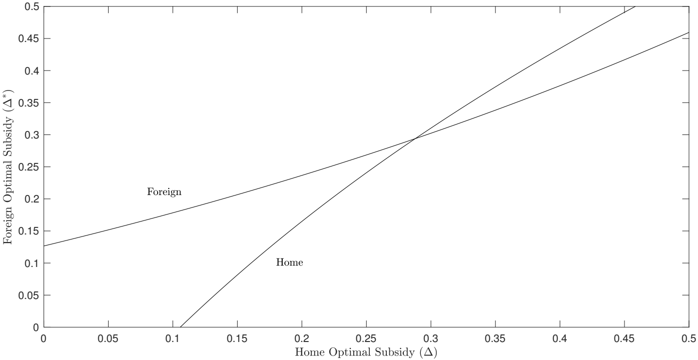
- The home and foreign reaction curves for setting R&D subsidies:

$$\left(\frac{c}{(\sigma-1)(\psi-\rho c)}+\frac{\gamma}{\rho}\right)\alpha g=\left((1-\Delta^*)(L^*+w^*H^*)+\frac{\psi N\rho c}{\psi-\rho c}\right)\frac{\Delta}{(1-\Delta)Z}+\frac{wH}{Z}$$

$$\left(\frac{c}{(\sigma-1)(\psi-\rho c)}+\frac{\gamma}{\rho}\right)\alpha g=\left((1-\Delta)\left(L+wH\right)+\frac{\psi N\rho c}{\psi-\rho c}\right)\frac{\Delta^*}{(1-\Delta^*)Z^*}+\frac{w^*H^*}{Z^*}$$

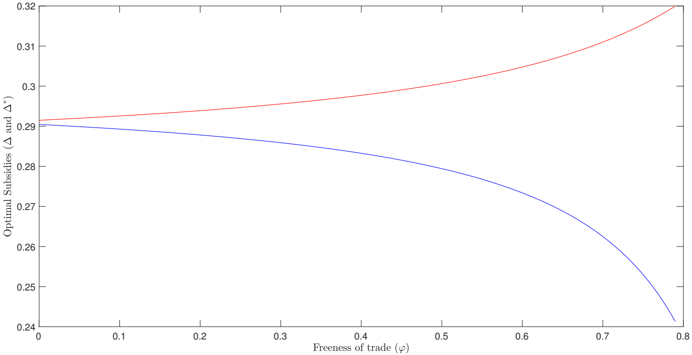
- A Nash equilibrium for optimal R&D subsidies requires that the home response function have a greater slope that the foreign response function in (Δ,Δ^*).

Optimal R&D Subsidies



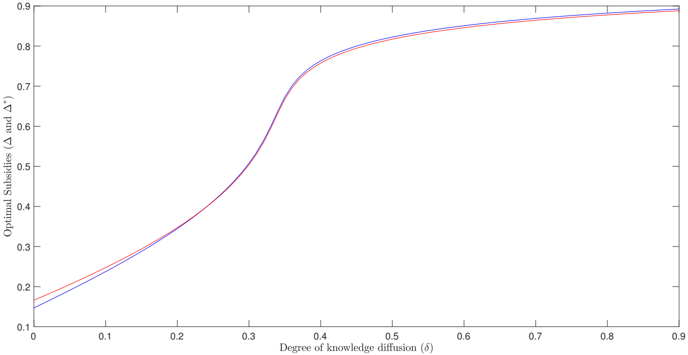
Parameter set: $\alpha = 1.2$ $\beta = 0.7$, $\delta = 0.15$, $\gamma = 0.15$, $\varphi = 0.2$, $\psi = 0.16$, $\rho = 0.02$, $\sigma = 4$, $Z = 10.5$, and $Z^* = 10$. The optimal subsidy rates are $\Delta = 0.288$, and $\Delta^* = 0.294$.

Optimal R&D Subsidies and Falling Trade Costs



Parameter set: $\alpha = 1.2$ $\beta = 0.7$, $\delta = 0.15$, $\gamma = 0.15$, $\varphi = 0.2$, $\psi = 0.16$, $\rho = 0.02$, $\sigma = 4$, $Z = 10.5$, and $Z^* = 10$. Home is blue and foreign is red.

Optimal R&D Subsidies and Rising Knowledge Diffusion



Parameter set: $\alpha = 1.2$ $\beta = 0.7$, $\delta = 0.15$, $\gamma = 0.15$, $\varphi = 0.2$, $\psi = 0.16$, $\rho = 0.02$, $\sigma = 4$, $Z = 10.5$, and $Z^* = 10$. Home is blue and foreign is red.

Conclusion

This papers considers how national R&D subsidy policy affects productivity growth through adjustments in geographic patterns of R&D activity in an endogenous growth model.

- Adjustments in national R&D subsidy policies affect market entry and productivity growth through the link between R&D location patterns and the cost of innovation. We find that R&D subsidies in either the larger or smaller country promote productivity growth.

- There appears to be an important link between optimal levels for national R&D subsidies and the market integration associated with lower trade costs and high knowledge diffusion.