innovation and growth in the global supply chains

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VERY PRIMARY AND INCOMPLETE

Abstract

we incorporate a sequential production process into the model of international product cycles to investigate the dynamic effects of global supply chains. final goods are subject to monopolistic competition and sequential production. each good is produced by a continuum of stages; at each stage, producing one unit of intermediate good requires one unit of the intermediate good produced in the previous stage and one unit of labor. labor is subject to mistakes, skilled labor has absolute advantage over all stages. innovation works in Schumpeterian way, i.e., growth stems from creative destruction and results in the upgrading of final good's quality. we characterize the BGP equilibrium under autarky and open economy, and find that: 1) trade liberalization in final good will .... 2) the emergence of global supply chain, characterized by intermediate good trade, will .... 3) improvement in world skill productivity, south's skill profile, innovation efficiency result in ...... moreover, trade friction, contract friction and intellectual property protection are also studied in these settings.

key words: innovation and imitation, global supply chains, product cycle, north-south trade

1 introduction

costinot et al. 2012, 2013

kremer 1993

antras and chor 2013

baldwin and

klette and kortum 2004

grossman and helpman 1991,1993

aghion and howitt 1992, 1998

aghion et al 2001, 2005

dinopoulos and segerstrom 1990, 2007

assignment reversal 2016

three strands of economic literature

1) global supply chains

2) trade, growth and wage inequality

3) rise of china

2 a benchmark model

2.1 demand and supply

2.1.1 endowment

two countries $\{N, S\}$

two skill category $\{l, h\}$

each with measure 1 of total labor endowment, supplied elastically

but differ in two respects:

i) skill abundance

ii) innovation capability

2.1.2 consumer

household's discounted utility function:

$$u_t = \int_t^\infty e^{-\rho(\tau - t)} \log y_\tau d\tau$$

where instantaneous utility is given by Cobb-Douglas function with quality component:

$$\log y_t = \int_0^1 \log[\Sigma_m q_m(j) x_{mt}(j)] dj$$

quality ladder: $q_0(j) = 1$, and $q_m(j) = \gamma^m$, with $\gamma > 1$, $m = 0, 1, 2, \ldots$

$$x_{mt}(j) = \begin{cases} E(t)/p_{mt}(j) & for\ m = \tilde{m}(j) \\ 0 & otherwise \end{cases}$$

$$p = exp\{\int_0^1 \log[\tilde{p}(j)/\tilde{q}(j)] dj\}$$

$$\frac{\dot{E}}{E} = r - \rho$$

choose aggregate spending to serve as numeraire:

$$E(t) = 1 \ for \ all \ t$$

then

$$r(t) = \rho \ for \ all \ t$$

Bertrand competition with the following tie breaking rule:

when quality-adjust price is even between new and old product, consumers always choose new

then Bertrand-Nash equilibrium yield limit pricing rule:

$$p = \gamma c$$

$$x = 1/\gamma c$$

where c is the second best's production cost, as we show in next subsection, all producers share the same cost, as a function of wage structure.

so profit is

$$\pi = 1 - 1/\gamma$$

only the highest quality producer is active

2.2 sequential production

now lets focus on the problem of the sequential production of final good.

consider skill level denoted by $c \in \{l, h\}$

low skill labor can only engage in production stages, while high skill labor can also take R&D jobs.

level c labor: L_c and w_c

individual firm takes wage as given, and choose labor demand for production

all producers, no matter in what sector and quality category, has to undertake a continuum stage $s \in (0, 1]$ to produce final good.

however, intermediate good is sector specific, and the quality of intermediate good correspond to the firm's quality level. so one unit stage $s \in (0, 1]$ intermediate good of firm $q_m(j)$ can substitute $q_m(j)$ units stage s intermediate good of firm $q_0(j) = 1$ perfectly, but cannot substitute any stage s' intermediate good, no matter how many units.

only final good provide utility to consumers

at each stage, producing one unit of intermediate good requires one unit of the intermediate good produced in the previous stage and one unit of labor

Poisson mistake rate $\lambda_c > 0$, assume λ_c is strictly decreasing in c.

then we have

$$x(s+ds) = (1-\lambda_c ds)x(s)$$

firm's cost minimization problem to produce one unit final good is

$$\min_{l_1,h_1} c = (w_l l_1 + w_h h_1)$$

s.t.

$$x(1) = 1$$

note that high skill labor is more productive at any stage, then the nature of sequential production requires positive assortative matching. firm must choose a stage $s^* \in [0,1]$ such that low skill labor produce at $(0, s^*]$, while high skill $(s^*, 1]$

then the quantity of intermediate good satisfies

$$x(s) = \begin{cases} e^{\lambda_l(s^*-s)+\lambda_h(1-s^*)} & 0 < s \leq s^* \\ e^{\lambda_h(1-s)} & s^* < s \leq 1 \end{cases}$$

labor requirement per unit product along the supply chain satisfies:

$\begin{cases} \int_0^{s^*} x(s)ds & = l_1 \\ \int_{s^*}^1 x(s)ds & = h_1 \end{cases}$

then labor could be expressed as function of s^*:

$l_1 = (e^{(\lambda_l-\lambda_h)s^*} - e^{-\lambda_h s^*})e^{\lambda_h}/\lambda_l$

$h_1 = (e^{-\lambda_h s^*} - e^{-\lambda_h})e^{\lambda_h}/\lambda_h$

substitute into cost function:

$c = e^{\lambda_h}[\frac{w_l}{\lambda_l}(e^{(\lambda_l-\lambda_h)s^*} - e^{-\lambda_h s^*}) + \frac{w_h}{\lambda_h}(e^{-\lambda_h s^*} - e^{-\lambda_h})]$

conditional on parameter value, we have

$$s^* = \begin{cases} 0 & when\ w_h \leq w_l \\ -\frac{1}{\lambda_l}\log\left[\frac{\frac{w_l}{\lambda_l}(\lambda_l-\lambda_h)}{(\frac{w_h}{\lambda_h}-\frac{w_l}{\lambda_l})\lambda_h}\right] & when\ w_l < w_h \leq \frac{(\lambda_l-\lambda_h)e^{\lambda_l}+\lambda_h}{\lambda_l}w_l \\ 1 & when\ \frac{(\lambda_l-\lambda_h)e^{\lambda_l}+\lambda_h}{\lambda_l}w_l < w_h \end{cases}$$

since low skill labor is supplied in-elastically, while high skill labor could undertake research work, case one never happens. and we are specially interested in the second and third case.

in the second case, cost function

$$c = e^{\lambda_h}\left[\frac{w_l}{\lambda_l}\left(\frac{\frac{w_l}{\lambda_l}(\lambda_l-\lambda_h)}{(\frac{w_h}{\lambda_h}-\frac{w_l}{\lambda_l})\lambda_h}\right)^{(\lambda_l-\lambda_h)/\lambda_l} + (\frac{w_h}{\lambda_h}-\frac{w_l}{\lambda_l})\left(\frac{\frac{w_l}{\lambda_l}(\lambda_l-\lambda_h)}{(\frac{w_h}{\lambda_h}-\frac{w_l}{\lambda_l})\lambda_h}\right)^{-\lambda_h/\lambda_l} - \frac{w_h}{\lambda_h}e^{-\lambda_h}\right]$$

total high skill labor demand:

$$L_l = xl_1 = \frac{l_1}{\gamma c}$$

total low skill labor demand:

$$L_h = xh_1 = \frac{h_1}{\gamma c}$$

in the third case, cost function

$$c = \frac{w_l}{\lambda_l}(e^{\lambda_l} - 1)$$

2.3 innovation mechanics

firm can use n unit high-skill labor into R&D, which results in an innovation with Poisson arriving rate θn

no-arbitrage condition

$$w_h \geq \theta v \ with\ equality\ whenever\ \iota > 0$$

value function

$$rv = \pi + \dot{v} - n\theta v$$

labor market clearing

$$n + L_h = h$$

$$L_l = l$$

2.4 autarky equilibrium

DEFINITION 1 (autarky equilibrium)

an autarky equilibrium is a tuple $(r, p, x, L_l, L_h, s^*, w_h, w_l, n)$ such that:

a) given the available quality and price of any good, consumer's static optimization problem

b) consumer intertemporal optimization problem

c) given consumer choice and market structure, monopolist leader optimally set price, which yields limit price strategy

d) given wage structure (w_h, w_l), firm optimally chooses critical stage s^*

e) given firm's optimal choice s^*, the demand for high and low skill labor (L_l, L_h) to undertake production chain is settled

f) given high skill wage w_h, no one can make positive profit by investing in R&D

g) the discounted value of a monopolistic firm is constant

h) labor market clears

in fact we can express the equilibrium as three equations involving w_h, w_l, n:

1) no arbitrage

$$w_h = \frac{\theta(1 - 1/\gamma)}{r + \theta n}$$

2) high labor

$$n + \frac{h_1(s^*(w_h, w_l))}{\gamma c(w_h, w_l)} = h$$

3) low labor

$$\frac{l_1(s^*(w_h, w_l))}{\gamma c(w_h, w_l)} = l$$

2.5 comparative statics

2.5.1 skill abundance

2.5.2 skill productivity

2.5.3 research efficiency

3 a simple product cycle model

labor and intermediate good is immobile, while final good is mobile across the border

we relax the assumption about intermediate good later, which allows the global value chain emerge.

firms at country $\chi \in \{N, S\}$ taking wage structure (w_h^χ, w_l^χ) as given, choose the minimum unit cost c^χ and critical stage $s^{\chi *}$ as functions of wage structure. labor demand per unit good is also pinned down by l_1^χ and h_1^χ.

note20160705:

here, we suppose that south only have low skill labors

see appendix for allowing south to have (relatively less) high skill labor

high skill labor can innovate and imitate, low skill labor can imitate, but cannot innovate

we suppose that the productivity of high and low skill labor on imitation is same

two types of market structure

1) north lead, south follow:

north produce, south imitate

2) north and south same:

south produce, north innovate

according to aghion et al. 2001, 2005, we assume max tech gap equals one. then leader will never innovate

only two type of industries:

$$\xi^N + \xi^S = 1$$

according to Bertrand-Nash equilibrium in section 2, we have

$$\pi^S = \frac{c^N - c^S}{c^N}$$

$$\pi^N = \frac{\gamma c^S - c^N}{\gamma c^S}$$

following grossman and helpman 1991, 1993, and for the sake of simplicity, we assume that everyone can imitate, but only the former leader can innovate (this assumption eliminates the third case, in which north followers can also update technology, see appendix)

then only the south would imitate for positive profit
free entry in research sector

$$\theta_S v^S \leq w_h^S,\ with\ equality\ whenever\ n^{imit} > 0$$

$$\theta_N v^N \leq w_h^N,\ with\ equality\ whenever\ n^{inno} > 0$$

value function

$$r^S v^S = \pi^S + \dot{v}^S - n^{inno}\theta_S v^S$$

$$r^N v^N = \pi^N + \dot{v}^N - n^{imit}\theta_N v^N$$

where n^{inno} is the researchers employed by the former north leaders
$n^{imit}$is the researchers employed by the south imitators
labor markets clear

$$n^{inno}\xi^S + \frac{h_1^N}{\gamma c^S}\xi^N = h^N$$

$$n^{imit}\xi^N + \frac{h_1^S}{c^N}\xi^S = h^S$$

$$\frac{l_1^N}{\gamma c^S}\xi^N = l^N$$

$$\frac{l_1^S}{c^N}\xi^S = l^S$$

steady state equilibrium

$$\theta_S n^{imit}\xi^N = \theta_N n^{inno}\xi^S$$

4 the emergence of global supply chain

the trend that:
1) country level income inequality decreases
while
2) individual and group level income inequality increases

4.1 intermediate good trade

now, we allow intermediate good trade
active north firm can import intermediate good from south
(question: can active south firm also undertake task separation? my answer is no, since the technology it holds is the same as its north counterpart)
important assumption:
ONLY LEADING NORTHERN FIRMS CAN ORGANIZE A GLOBAL SUPPLY CHAIN
(this assumption is relaxed in appendix 4)

suppose wage gap and quality ladder is sufficient large to ensure only one time of vertical specialization:

.png

where $(0, s_1]$ employ south low skill

$(s_1, s_2]$ employ south high skill

$(s_2, s_3]$ employ north low skill

$(s_3, 1]$ employ north high skill

so north leader only have to import stage s_2 intermediate good

cost minimization problem of an integrated leading firm in north:

$$\min_{l_1^{Sint}, h_1^{Sint}, l_1^{Nint}, h_1^{Nint}} c^{int} = w_l^S l_1^{Sint} + w_h^S h_1^{Sint} + w_l^N l_1^{Nint} + w_h^N h_1^{Nint}$$

s.t.

$$x(1) = 1$$

sequential production

$$x(s) = \begin{cases} \gamma e^{\lambda_l(s_1 - s) + \lambda_h(s_2 - s_1) + \lambda_l(s_3 - s_2) + \lambda_h(1 - s_3)} & 0 < s \leq s_1 \\ \gamma e^{\lambda_h(s_2 - s) + \lambda_l(s_3 - s_2) + \lambda_h(1 - s_3)} & s_1 < s \leq s_2 \\ e^{\lambda_l(s_3 - s) + \lambda_h(1 - s_3)} & s_2 < s \leq s_3 \\ e^{\lambda_h(1 - s)} & s_3 < s \leq 1 \end{cases}$$

the multiplication of γ reflects the fact that north leader hold the advantage of technology superiority.

(note: should we multiply γ? I have been considering this question for a while, and my answer is not sure. the key to this question is whether technology is separable: can north firm only teach south firm to undertake certain tasks with most advanced technology but keep the whole technology in secret? or would north firm be willing to teach? there are threats to lose technology leadership by spillover effects. for technical consideration, not multiplying γ always results in factor price equalization for low skill labor; for high skill, unless there is full specialization in innovation and/or imitation, then FPE also holds)

labor requirement

$$\int_0^{s_1} x(s) ds = l_1^{Sint}$$

we can express labor demand as function of s_1, s_2, s_3

substitute into cost function, then first order condition yield optimal stages s_1^*, s_2^*, s_3^* as function of wages

(see appendix for more details)

then unit cost is also function of wages, we denote as c^{int}

note: integration by gsc always yields lower cost (partial equilibrium effect)

the cost of a south firm is c^S, as function ONLY of south wage structure, irrespective of its technical position, is the same

the cost of a north firm without technology advantage is c^N, as function ONLY of north wage structure

note: function form is the same, but wage structure has been changed by gsc (general equilibrium effect)

4.2 steady-state equilibrium

we restrict our attention to the special case where 0<s1<s2<s3<1 holds strictly (see appendix for more general cases)

now

$$\xi^{Nint} + \xi^S = 1$$

$$\pi^{Nint} = \frac{\gamma c^S - c^{int}}{\gamma c^S}$$

but $\pi^S = \dfrac{c^N - c^S}{c^N}$ is unchanged

free entry condition and value function is also unchanged:

$$\theta_S v^S \leq w_h^S, \ with\ equality\ whenever\ n^{imit} > 0$$

$$\theta_N v^{Nint} \leq w_h^N, \ with\ equality\ whenever\ n^{inno} > 0$$

$$r^S v^S = \pi^S + \dot{v}^S - n^{inno}\theta_S v^S$$

$$r^N v^{Nint} = \pi^{Nint} + \dot{v}^{Nint} - n^{imit}\theta_N v^{Nint}$$

north labor market:

$$n^{inno}\xi^S + \frac{h_1^{Nint}}{\gamma c^S}\xi^{Nint} = h^N$$

$$\frac{l_1^{Nint}}{\gamma c^S}\xi^{Nint} = l^N$$

south labor market has been changed drastically:

$$n^{imit}\xi^{Nint} + \frac{h_1^{Sint}}{\gamma c^S}\xi^{Nint} + \frac{h_1^S}{c^N}\xi^S = h^S$$

$$\frac{l_1^{Sint}}{\gamma c^S}\xi^{Nint} + \frac{l_1^S}{c^N}\xi^S = l^S$$

industry dynamics

$$\theta_S n^{imit} \xi^{Nint} = \theta_N n^{inno} \xi^S$$

4.3 the effect of the emergence of gsc, compared to section 3

4.3.1 direct effect

general equilibrium effect: on wage structure $w_l^N, w_h^N, w_l^S, w_h^S$

partial equilibrium effect: on vertical specialization $s_1^*, s_2^*, s_3^*, s^{S*}$, production cost c^S, c^N, c^{Nint} and profit π^S, π^{Nint}

4.3.2 indirect effect

on innovation and imitation intensity n^{inno}, n^{imit} (through labor market and no arbitrage condition)

on industry allocation ξ^{Nint}, ξ^S (through steady state condition)

on growth and welfare $g = \theta_N n^{inno}$ (Schumpeterian growth)

4.4 trade costs and contract frictions

5 policy analysis: education, subsidy to innovation and IP protection

5.1 expansion of education in south

increase south skill abundance, i.e., $h \uparrow$

5.2 subsidy to innovation in north

decrease innovation cost, i.e., $\theta_N \uparrow$

5.3 IP protection in south

increase imitation cost, i.e., $\theta_S \downarrow$

6 extensions: skill-biased technology, competition intensity and knowledge spillover

6.1 what if technology only enhances the productivity of high skill labor?

6.2 is there an invert U relationship between competition and innovation?

Aghion et al. 2001

two leveled firm can collude. more intense competition lowers the possibility of collusion

6.3 what if south follower can learn from vertical specialization?

that is, $\theta_{Sint} > \theta_S$

7 conclusion

References

[1] Costinot, Arnaud, Jonathan Vogel, and Su Wang. ”An elementary theory of global supply chains.” The Review of Economic Studies 80.1 (2013): 109-144.

[2] Costinot, Arnaud, Jonathan Vogel, and Su Wang. ”Global Supply Chains and Wage Inequality.” The American Economic Review 102.3 (2012): 396-401.

[3] etc.

Appendix

A1 sequential production

we provide the solution to the cost minimization problem of a representative supply chain organizer in details

A2 positive innovation and imitation

we provide conditions under which equilibrium innovation and imitation is positive

A3 innovating north followers

then there are three types of market structure:

1) north lead, north follow
2) north lead, south follow
3) south equals north

A4 vertical specialization

A4.1 another global supply chain by leveled firms

that is, not only north leader can organize global supply chain, but those without technology leadership can also use gsc to reduce cost

A4.2 the possibility of multi times intermediate good trade

that is, it is possible to be several times of cross border trade of intermediate good, for instance:

$(0, s_1]$ produced by south low skill, export to north
$(s_1, s_2]$produced by north low skill, export to south
$(s_2, s_3]$ produced by south high skill, export to north
$(s_3, 1]$ produced by north high skill, for domestic and foreign consumption