Intergenerational Bargaining in Technology Adoption

Byeongju Jeong

CERGE-EI
POB 882, Politickych veznu 7
111 21 Prague 1
Czech Republic

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ABSTRACT

I study the choice of technology adoption in an environment where human capital is transmitted from the old to the young generation but the young generation can opt out for a new technology. The adoption and matching decisions are made in a sequential intergenerational bargaining. Since technology adoption benefits future generations who do not participate in the bargaining, there is an inherent bias toward preserving the current technology. The main result is that economic integration (i.e., sharing of the frontier technology among countries) promotes growth while political integration (i.e., merging of countries into a single bargaining) promotes stagnation.

1. Introduction

I study the choice of technology adoption in an environment where human capital is transmitted from the old to the young generation but the young generation can opt out for a new technology. The adoption of new technology raises the productivity of the young and future generations while it depreciates the value of existing human capital. The choice of technology adoption is made in each period in an intergenerational bargaining. Since technology adoption benefits future generations who do not participate in the bargaining, there is an inherent bias toward preserving the current technology. The current generations have the incentive to preserve the current technology if the average human capital of the old generation is close enough to the frontier technology.

I examine variations of the environment along two dimensions. First, I consider economic integration, that is, the sharing of the frontier technology among economies initially separated from each other. A sufficient condition for a perpetual growth in economic integration is the diversity of human capital distribution among countries: the growth occurs as long as the country furthest from the frontier technology has the incentive to adopt the frontier technology. Second, I consider political integration, that is, the merging of countries into a political union with a single intergenerational bargaining. The political union forms when the average human capital in the world is sufficiently close to the frontier technology so that stagnation is beneficial to the current generations. Thus political integration always leads to a stagnation.

The modern economic growth of the world may reflect the growth imperative that each country faces under economic integraion and politial fragmentation. The economic integration defined as the sharing of the frontier technology was probably at the continental scale a couple of hundred years ago. The sustained growth of European countries then may have to do with political fragmentation. This view can be found in Jones (1981) and Mokyr (1990) among others. A politcally integrated China, on the other hand, stagnated then and in preceding centuries. More recently, economic integraion is at the global scale and stagnation is not a sustainable option for any countries. The transition of the former-communist countries in the 1990's and the structural adjustments of the Asian countries in the aftermath of the debt crisis in the late 1990's provide examples.

The modeling exercise builds on the vintage human capital model of Chari and Hopenhayn (1991) and the political economy model of Krusell and Rios-Rull (1996). In comparison to the latter, the society-wide decision process is modeled as a bargaining rather than a voting. The bargainig delivers efficient adoption and matching behavior for the current generations and assigns a payoff to each generation. The aggregate path of the economy is independent of individual activities and payoffs as long as they aggregate to the bargaining outcome. I consider efficient bargaining as a means of abstracting from variations in institutional details that add up to deliver efficient adoption and matching behavior.

2. The Model Economy: A Single Country

There are two overlapping generations in each period. There are many people in each generation whose number is normalized to one. Human capital embodies technology with a higher level of h associated with a superior technology. Technologies are ordered such that the ratio of the human capital levels associated with any two adjacent technologies is fixed at $\lambda > 1$. Let $\{h_s\}$ denote the ordered set of human capital levels where h_0 is associated with the frontier technology available for adoption: $h_s/h_{s+1} = \lambda$ for all s. Let n_s, $s \geq 1$, denote the fraction of old people with human capital h_s. The young generation is endowed with no human capital. Production takes place on an individual basis or in a team of two people, one from each generation. An old person with human capital h_s alone produces ϕh_s units of output. A team of an old person with human capital h_s produces h_s units of output. Within a team, the young person inherits the human capital of the old person in the next period. A young person alone produces no output but obtains human capital h_0 in the next period. Thus the adoption of the frontier technology is individual-specific and requires one period of time with no output. Assume that $\phi < 1$, which implies that team production has advantage over individual production, holding technology.

Let $\tilde{n}_s$, $s \geq 0$, denote the fraction of young people who will have human capital h_s when old. Let $n \equiv (n_1, n_2, n_3, \ldots)$ and $\tilde{n} \equiv (\tilde{n}_0, \tilde{n}_1, \tilde{n}_2, \ldots)$. Feasibility requires: $\tilde{n}_s \leq n_s$ for all $s \geq 1$. Let $\Lambda h_0(h_0, \tilde{n})$ denote updating rule of the frontier technology. The frontier technology is an innovation of the previously adopted technology at the rate λ:

$$\Lambda h_0(h_0, \tilde{n}) = \begin{cases} h_0 & \text{if } \tilde{n}_0 = 0; \\ \lambda h_0 & \text{if } \tilde{n}_0 > 0. \end{cases} \tag{1}$$

The aggregate output is:

$$Y(h_0, n, \tilde{n}) = \sum_{s=1}^{\infty} \big(h_s \tilde{n}_s + \phi h_s (n_s - \tilde{n}_s)\big). \tag{2}$$

Let $\Lambda n(h_0, \tilde{n})$ denote the updating rule of n: $\Lambda n(h_0, \tilde{n}) = \tilde{n} = (\tilde{n}_0, \tilde{n}_1, \tilde{n}_2, \ldots)$ if $\Lambda h_0(h_0, \tilde{n})$ $= \lambda h_0$; and $\Lambda n(h_0, \tilde{n}) = (\tilde{n}_1, \tilde{n}_2, \tilde{n}_3, \ldots)$ if $\Lambda h_0(h_0, \tilde{n}) = h_0$. Let $V_o(h_0, n)$ denote the aggregate utility of the old generation, and $V_y(h_0, n)$ the aggregate utility of the young generation. Let $W(h_0, n, \tilde{n})$ deonte the aggregate utility across the young and the old generations conditional on $\tilde{n}$:

$$W(h_0, n, \tilde{n}) = Y(h_0, n, \tilde{n}) + \beta V_o(\Lambda h_0(h_0, \tilde{n}), \Lambda n(h_0, \tilde{n})), \tag{3}$$

where β is the discount rate. Note that the aggregate utility includes the discounted utility of the young generation's utility when it becomes old.

The adoption and matching behavior and the utilities of generations are determined in a sequential intergenerational bargaining. Let $\bar{V}_o(h_0, n)$ denote the reservation utility of the old generation; and $\bar{V}_y(h_0)$ the reservation utility of the young generation: $\bar{V}_o(h_0, n) = Y(h_0, n, \bar{n}) = \sum_{s=1}^{\infty} \phi h_s n_s$ and $\bar{V}_y(h_0) = \beta V_o(\lambda h_0, \bar{n})$, where $\bar{n} \equiv (1, 0, 0, \ldots)$. The reservation utilities obtain when there are no matches across the generations: each old person works alone and each young person adopts the frontier technology. Let $g(h_0, n)$ denote the adoption and matching behavior, that is, a function from $\{(h_0, n)\}$ to $\{\tilde{n}\}$. This function and the utilities of generations solve the Nash bargaining problem: for all h_0 and n,

$$(g(h_0,n), V_o(h_0,n), V_y(h_0,n)) = \underset{\tilde{n},v_o,v_y}{\operatorname{argmax}} \left\{(v_o - \bar{V}_o(h_0,n))^{\mu}(v_y - \bar{V}_y(h_0))^{1-\mu}\right\}, \quad (4)$$

subject to $v_o + v_y \leq W(h_0,n,\tilde{n})$. Note that bargaining is across the generations; the individual utilities do not need to be specified. One interpretation is a collective bargaining between the generations. Given the ex-ante homogeneity among the young people, I could assume that the young generation's aggregate lifetime utility $V_y(h_0,n)$ is divided equally among the young people, which may involve an unequal division of output in each of the two periods of the lifetime. Given the updating rule of the frontier technology (1), an equilibrium is the utility functions, W, V_o, and V_y; the aggregate output function Y; and the adoption and matching behavior $g(h_0,n)$ that together satisfy (2),(3), and (4).

Now assume that scaling of human capital ditribution changes the equlibirium path only proportionately: for any h_0, n, and $\theta > 0$, $g(\theta h_0,n) = g(h_0,n)$ and $V_o(\theta h_0,n)/V_o(h_0,n)$ $= V_y(\theta h_0,n)/V_y(h_0,n) = \theta$. In other words, h_0 can be normalized to one. Given the tranferability of utility across the generations, (4) is equivalent to maximizing the aggregate utility and dividing the utility by μ and $1-\mu$ shares across the generations. Putting these things together, we can rewrite the value functions as:

$$\hat{W}(n) = \max\left\{\hat{Y}(n,(0,n)) + \beta\hat{V}_o(n),\ \max_{\tilde{n}\neq(0,n)}\left\{\hat{Y}(n,\tilde{n}) + \beta\lambda\hat{V}_o(\tilde{n})\right\}\right\} \quad (5)$$

and

$$\hat{V}_o(n) = \mu\cdot(\hat{W}(n) - \beta\lambda\hat{V}_o(\bar{n})) + (1-\mu)\cdot\hat{Y}(n,\bar{n}), \quad (6)$$

where $\hat{Y}(n,\tilde{n}) \equiv Y(1,n,\tilde{n})$.

In characterizing the equilibrium, I will focus on the states of the economy when the old generation's human capital is distributed over at most the two most recently adopted technologies: $n_1 + n_2 = 1$. Further, I will characterize the equilibrium mainly in terms of the productivity parameter ϕ and the distribution of human capital n since the value functions are linear in ϕ and n and analytical results are more easily obtained in terms of these parameters. Intuitively, a higher value of ϕ implies a lower output loss from production by an unmatched old person and would make the young people more likely to adopt the frontier technology. A higher value of n_1, equivalently a lower value of n_2, implies that the distribution of human capital among the old generation is more skewed toward the better of the two technologies currently in use, and would make the young people more likely to match with the old people. The effects of the innovation size parameter λ, the discount rate β, and the old generation's bargaining power μ on the equilibrium is more difficult to characterize explicitly. Intuitively, a higher value of innovation size parameter λ or the discount rate β would make the young more likely to adopt the frontier technology. The effect of the old generation's bargaining power μ is less obvious and perhaps surprising. Generally, a higher value of μ makes the young more likely to adopt the frontier technology since the young can expropriate a greater share of the return from adopting the frontier technology when they become old.

When $n_1 + n_2 = 1$, the equilibrium adoption and matching behavior is characterized as follows:

A. Unconditional Growth Equilibrium:

$$g^i(h_0, n) = (1, 0, 0, ...) \quad \text{for all } n \tag{7}$$

if $\phi \geq \bar{\phi}$, where $\bar{\phi} \equiv 1/(1 - \beta + \beta\lambda)$. In this equilibrium, there are no matches across the generations: each old person works alone and each young person adopts the frontier technology regardless of n. The resturn from adopting the frontier technology dominates any other considerations in this range of parameters.

B. Conditional Growth and Stagnation Equilibrium 1:

$$g(h_0, n) = \begin{cases} (1\ \ , 0\ \ , 0\ \ , ...) & \text{for } n_1 \in [0, \hat{n}] \\ (n_2, n_1, 0\ \ , ...) & \text{for } n_1 \in [\hat{n}, \check{n}] \\ (0\ \ , n_1, n_2, ...) & \text{for } n_1 \in [\check{n}, 1] \end{cases} \tag{8}$$

if $\hat{\phi} \leq \phi \leq \bar{\phi}$, where $\hat{\phi} \equiv (1-\beta\lambda\mu)/(1-\beta+\beta\lambda-\beta\lambda\mu)$; $\hat{n} \equiv \beta^2\lambda\mu^2/((1-\beta\lambda\mu)(1-\beta\mu+\beta\lambda\mu))$; $\check{n}$ is increasing in ϕ; $\check{n} = 1$ when $\phi = \bar{\phi}$; and $\check{n} = 1-\hat{n}$ when $\phi = \hat{\phi}$. In this equilibrium, the adoption and matching decisions depend on the distribution of human capital. There are no matches and each young person adopts the frontier technology if the distribution of human capital is skewed toward the worse of the two technologies currently in use. Everyone is matched and no young person adopts the frontier technology if the distribution of human capital is skewed toward the better of the two technologies. If the distribution of human capital is not skewed toward either technology, the old people with the better of the two technology are matched with the young people; the old people with the worse of the two technologies are not matched; and the remaining young people adopt the new technology.

C. Conditional Growth and Stagnation Equilibrium 2:

$$g(h_0, n) = \begin{cases} (n_2, n_1, 0\ \ , ...) & \text{for } n_1 \in [0, \check{n}] \\ (0\ \ , n_1, n_2, ...) & \text{for } n_1 \in [\check{n}, 1] \end{cases} \tag{9}$$

if $\tilde{\phi}_a \leq \phi \leq \hat{\phi}$, where $\tilde{\phi}_a \equiv (1-\beta\mu+\beta\lambda\mu-\beta\lambda^2\mu)/((1-\beta)(1-\beta\mu+\beta\lambda\mu)+\beta\lambda^2(1-\mu))$; $\check{n}$ is increasing in ϕ; $\check{n} = 1-\hat{n}$ when $\phi = \hat{\phi}$; and $\check{n} = 0$ when $\phi = \tilde{\phi}_a$. This equilibirum is the same as Conditional Growth and Stagnation Equilibrium 1 above except that the no-match-all-adopt case does not occur regardless of n.

D. Unconditional Stagnation Equilibrium:

$$g(h_0, n) = (0, n_1, n_2, ...) \quad \text{for all } n \tag{10}$$

if $\phi \leq \tilde{\phi}_a$. In this equilibrium, everyone is matched and no young person adopts the frontier technology regardless of n. Today's technology adoption allows tomorrow's young generation to adopt an even better technology so that a smaller share of surplus from a joint production accrues to tomorrow's old generation or, equivalently, today's young generation. The current generations can avoid such a loss by not adopting the frontier technology. In other words, stagnation carries a premium, i.e., the aggregate utility gain from holding the frontier technology. The stagnation premium dominates all other considerations in this range of parameters.

Given the parameter values and the initial distribution of human capital, I can derive the equilibirum path by repeatedly deriving $\tilde{n}$ using the above characterization of the quilibrium adoption and matching behavior and then updating h_0 and n using $\Lambda h_0(h_0, \tilde{n})$ and $\Lambda n(h_0, \tilde{n})$. Let $S_a^1 \equiv [0, \max\{\hat{n}, 1-\check{n}\}]$; $S_a^2 \equiv [\max\{\hat{n}, 1-\check{n}\}, \min\{\check{n}, 1-\hat{n}\}]$; and $S_a^3 \equiv [\min\{\check{n}, 1-\hat{n}\}, 1]$. I can derive $\max\{\hat{n}, 1-\check{n}\} = \min\{\check{n}, 1-\hat{n}\} = \check{n} = 1/2$ when $\phi = \check{\phi}_a \equiv (1-\beta\mu-\beta\lambda\mu(1-\beta\lambda\mu)(\lambda-1))/((1-\beta)(1-\beta\mu+\beta\lambda\mu)+\beta\lambda^2(1-\mu)(1+\beta\mu-\beta\lambda\mu))$. I can show:

Proposition 1. Assume that $n_1 + n_2 = 1$ and $\tilde{\phi}_a < \phi < \bar{\phi}$. The economy grows perpetually if $n_1 \in S_a^2$. The economy stagnates perpetually after at most two periods of growth if $n_1 \in S_a^1 \cup S_a^3$.

Proof: to be written.

3. The Model Economy: Multiple Countries

There are I number of countries, indexed by i, each of which faces the same adoption and matching environment as in Section 2, except that the frontier technology is shared across countries. Let n and $\tilde{n}$ denote the vectors of human capital distribution: $n \equiv (n^1, n^2, ..., n^I)$; $n^i \equiv (n_1^i, n_2^i, n_3^i, ...)$; $\tilde{n} \equiv (\tilde{n}^1, \tilde{n}^2, ..., \tilde{n}^I)$; and $\tilde{n}^i \equiv (\tilde{n}_0^i, \tilde{n}_1^i, \tilde{n}_2^i, ...)$. The updating rule of the frontier technology is:

$$\Lambda h_0(h_0, \tilde{n}) = \begin{cases} h_0 & \text{if } \max_i\{\tilde{n}_0^i\} = 0; \\ \lambda h_0 & \text{if } \max_i\{\tilde{n}_0^i\} > 0. \end{cases} \qquad (1)'$$

The aggregate output of country i is:

$$Y(h_0, n^i, \tilde{n}^i) = \sum_{s=1}^{\infty} \left(h_s \tilde{n}_s^i + \phi h_s (n_s^i - \tilde{n}_s^i) \right). \tag{2$'$}$$

The updating rule of n^i is $\Lambda n^i(h_0, \tilde{n}) = \tilde{n}^i = (\tilde{n}_0^i, \tilde{n}_1^i, \tilde{n}_2^i, ...)$ if $\Lambda h_0(h_0, \tilde{n}) = \lambda h_0$; and $\Lambda n^i(h_0, \tilde{n}) = (\tilde{n}_1^i, \tilde{n}_2^i, \tilde{n}_3^i, ...)$ if $\Lambda h_0(h_0, \tilde{n}) = h_0$. Let $V_o^i(h_0, n)$, $V_y^i(h_0, n)$, and $W^i(h_0, n^i, \tilde{n})$ denote the aggregate utilities. The aggregate utility of country i is:

$$W^i(h_0, n^i, \tilde{n}) = Y(h_0, n^i, \tilde{n}^i) + \beta V_o^i(\Lambda h_0(h_0, \tilde{n}), \{\Lambda n^i(h_0, \tilde{n})\}). \tag{3$'$}$$

Let $g^i(h_0, n)$ denote the adoption and matching behavior, that is, a function from $\{(h_0, n)\}$ to $\{\tilde{n}^i\}$. The reservation utilities are: $\bar{V}_o(h_0, n^i) = Y(h_0, n^i, \bar{n}) = \sum_{s=1}^{\infty} \phi h_s n_s^i$ and $\bar{V}_y^i(h_0, n) = \beta V_o^i(\lambda h_0, G^{-i}(h_0, n, \bar{n}))$, where $\bar{n} \equiv (1, 0, 0, \ldots)$ and $G^{-i}(h_0, n, \tilde{n}^i) \equiv (...,$ $g^{i-1}(h_0, n), \tilde{n}^i, g^{i+1}(h_0, n), ...)$. These functions solve the Nash bargaining problem: for all h_0 and n,

$$(g^i(h_0, n), V_o^i(h_0, n), V_y^i(h_0, n)) = \operatorname*{argmax}_{\tilde{n}^i, v_o, v_y} \left\{ (v_o - \bar{V}_o(h_0, n^i))^{\mu} (v_y - \bar{V}_y(h_0, n))^{1-\mu} \right\}, \tag{4$'$}$$

subject to $v_o + v_y \leq W^i(h_0, n^i, G^{-i}(h_0, n, \tilde{n}^i))$. Given the updating rule of the frontier technology $(1)'$, an equilibrium is the utility functions, $\{W^i\}$, $\{V_o^i\}$, and $\{V_y^i\}$; the aggregate output function Y; and the adoption and matching behavior $\{g^i(h_0, n)\}$ that together satisfy $(2)'$, $(3)'$, and $(4)'$.

Assume that scaling of human capital ditribution changes the equlibirium path only proportionately as in Section 2: for any h_0, n, and $\theta > 0$, $g^i(\theta h_0, 3bpn) = g(h_0, n)$ and $V_o^i(\theta h_0, n)/V_o^i(h_0, n) = V_y^i(\theta h_0, n)/V_y^i(h_0, n) = \theta$. The value functions can be rewritten as:

$$\check{W}^i(n) = \max_{\tilde{n}^i} \left\{ \check{Y}(n, \tilde{n}^i) + \beta \lambda \check{V}_o^i(\check{G}^{-i}(n, \tilde{n}^i)) \right\} \tag{11}$$

if $\max_{j \neq i}\{g_0^j(n)\} > 0$; and

$$\check{W}^i(n) = \max \left\{ \check{Y}(n, (0, n)) + \beta \check{V}_o^i(n), \max_{\tilde{n}^i \neq (0, n)} \left\{ \check{Y}(n, \tilde{n}^i) + \beta \lambda \check{V}_o^i(\check{G}^{-i}(n, \tilde{n}^i)) \right\} \right\} \tag{12}$$

if $\max_{j \neq i}\{g_0^j(n)\} = 0$, where

$$\check{V}_o^i(n) = \mu \cdot (\check{W}^i(n) - \beta\lambda \check{V}_o^i(\check{G}^{-i}(n, \tilde{n}^i)) + (1-\mu) \cdot \check{Y}(n, \bar{n}), \tag{13}$$

$\check{G}^{-i}(n, \tilde{n}^i) \equiv G^{-i}(1, n, \tilde{n}^i)$, and $\check{Y}(n, \tilde{n}) \equiv Y(1, n, \tilde{n})$.

Consider the states of the world economy when the old generation's human capital is distributed over at most the two most recently adopted technologies: $n_1^i + n_2^i = 1$ for all i. Further, focus on the symmetric equilibrium: $\check{W}^i = \check{W}^j$, $\check{V}_o^i = \check{V}_o^j$, and $g^i = g^j$ for all i and j. The equilibrium adoption and matching behavior is characterized as follows:

A. Unconditional Growth World Equilibrium 1:

$$g^i(h_0, n) = (1, 0, 0, ...) \quad \text{for all } n \tag{14}$$

if $\phi \geq \bar{\phi}$, where $\bar{\phi} \equiv 1/(1 - \beta + \beta\lambda)$. In this equilibrium, there are no matches across the generations: each old person works alone and each young person adopts the frontier technology regardless of n. The resturn from adopting the frontier technology dominates any other considerations in this range of parameters, as in the Unconditional Growth Equilibrium in Section 2.

B. Unconditional Growth World Equilibrium 2:

$$g^i(n) = (n_2^i, n_1^i, 0, ...) \quad \text{for all } n \tag{15}$$

if $\tilde{\phi}_w \leq \phi \leq \bar{\phi}$, where $\tilde{\phi}_w \equiv (1 - \beta\mu - \beta\lambda^2\mu(1-\beta\lambda\mu))/((1-\beta)(1-\beta\mu) + \beta\lambda^2(1-\mu)(1-\beta\lambda\mu))$ and $\tilde{\phi}_a < \tilde{\phi}_w < \check{\phi}_a$. In this equilibrium, the old people with the better of the two technology are matched with the young people; the old people with the worse of the two technologies are not matched; and the remaining young people adopt the new technology regardless of n. This equilibrium is different from any equilibria in Section 2. From the perspective of a single country, the frontier of technology advances exogenously regardless of its own adoption decision. Therefore, there is no stagnation premium and every country adopts the frontier technology, which in turn validates the advancement of the frontier technology.

C. Conditional Growth and Stagnation World Equilibrium 1:

$$g^i(n) = \begin{cases} (1 \ \ ,0 \ \ ,0 \ \ ,...) & \text{if } n_1^i, n_1^j \in [0, \hat{m}] \\ (0 \ \ ,n_1^i, n_2^i, ...) & \text{if } n_1^i, n_1^j \in [\check{m}, 1] \\ (n_2^i, n_1^i, 0 \ \ ,...) & \text{otherwise} \end{cases} \tag{16}$$

if $\hat{\phi} \leq \phi \leq \bar{\phi}$, where $\hat{\phi} \equiv (1-\beta\lambda\mu)/(1-\beta+\beta\lambda-\beta\lambda\mu)$; $\tilde{\phi}_w < \hat{\phi} < \bar{\phi}$; $\hat{m} \equiv \beta^2\lambda\mu^2/(1-\beta\mu-\beta^2\lambda^2\mu^2)$; $\hat{m} > \hat{n}$; $\check{m} < \check{n}$; $\check{m}$ is increasing in ϕ; $\check{m} = 1$ when $\phi = \bar{\phi}$; and $\check{m} = 1 - \hat{m}$ when $\phi = \hat{\phi}$. In this equilibrium, the adoption and matching decisions depend on the distribution of human capital, as in the Conditional Growth and Stagnation Equilibrium 1 in Section 2. there are no matches and each young person adopts the frontier technology if the distribution of human capital is skewed toward the worse of the two technologies currently in use. Everyone is matched and no young person adopts the frontier technology if the distribution of human capital is skewed toward the better of the two technologies. If the distribution of human capital is not skewed toward either technology, the old people with the better of the two technology are matched with the young people; the old people with the worse of the two technologies are not matched; and the remaining young people adopt the new technology.

D. Conditional Growth and Stagnation World Equilibrium 2:

$$g^i(n) = \begin{cases} (0 \ \ ,n_1^i, n_2^i, ...) & \text{if } n_1^i, n_1^j \in [\check{m}, 1] \\ (n_2, n_1^i, 0 \ \ ,...) & \text{otherwise} \end{cases} \tag{17}$$

if $\tilde{\phi}_w < \phi \leq \hat{\phi}$, where $\check{m} < \check{n}$; $\check{m}$ is increasing in ϕ; $\check{m} = 1 - \hat{m}$ when $\phi = \hat{\phi}$; and $\check{m} \to 0$ as $\phi \to \tilde{\phi}_w$. This equilibirum is the same as Conditional Growth and Stagnation World Equilibrium 1 above except that the no-match-all-adopt case does not occur regardless of n; it is also analogous to the Conditional Growth and Stagnation Equilibrium 2 in Section 2.

If $\phi \leq \tilde{\phi}_w$, it is more complicated to characterize the equilibrium. In particular, the symmetric equilibrium does not exist depending on the parameter values. As in Section 2, The equilibirum path can be derived from the above characterization of the equilibrium adoption and matching behavior and the updating rules $\Lambda h_0(h_0, \tilde{n})$ and $\Lambda n^i(h_0, \tilde{n})$. Let $S_w^1 \equiv [0, \max\{\hat{m}, 1-\check{m}\}]$; $S_w^2 \equiv [\max\{\hat{m}, 1-\check{m}\}, \min\{\check{m}, 1-\hat{m}\}]$; and $S_w^3 \equiv [\min\{\check{m}, 1-\hat{m}\}, 1]$. I can derive $\max\{\hat{m}, 1-\check{m}\} = \min\{\check{m}, 1-\hat{m}\} = \check{m} = 1/2$ when $\phi = \check{\phi}_w \equiv ((1-\beta\mu)(1+2\beta\lambda\mu) - \beta\lambda^2\mu(1-\beta^2\lambda^2\mu^2))/((1-\beta)(1-\beta\mu)(1+2\beta\lambda\mu) + \beta\lambda^2((1-\mu)(1-\beta^2\lambda^2\mu^2) + \beta\mu(1-\beta\mu)))$. I can show:

Proposition 2. Assume that $n_1 + n_2 = 1$ and $\tilde{\phi}_w < \phi < \bar{\phi}$. Discard asymmetric equilibria. The world economy grows perpetually if $\{n_1^i\} \not\subset S_w^1$ and $\{n_1^i\} \not\subset S_w^3$. The world economy either grows perpetually or stagnates perpetually after at most two periods of growth if $\{n_1^i\} \subset S_w^1$ or $\{n_1^i\} \subset S_w^3$.

Proof: to be written.

Note that the diversity of countries in terms of human capital ditribution promotes growth in the world. The intuition is that with diversity comes differential gains from adopting the frontier technology across countries and the frontier technology advances as long as it is advantageous to at least one country. Also note the mulitiple equilibria when the diversity is limited: stagnation is advantageous to a country as long as other countries stagnate but growth is advantageous if others grow. The intuition is that the current generations of a country can enjoy the stagnation premium by not adopting the frontier technology if and only if the other countries do not adopt the frontier technology either.

4. Comparison of World Economies

I compare three versions of the world economy. The first world economy is a collection of countries, each in autarky as described in Section 3. The second world economy is a collection of countries that share the frontier technology but are separate in bargaining as described in Section 4. The third world economy is a political union with a single frontier technology and a single bargaining, equivalent to a single autarky in Section 3. I consider economic integration as the transition from the first to the second world economy, and political integration as the transition from the second to the third world economy. I assume that a transition is an unexpected or a small-probability event so that the evaluations of the transition can be done in terms of the value functions in Sections 2 and 3 in approximation.

4.1 Economic Integration

Consider the transition of the world economy from a collection of countries, $\{1, 2, ..., I\}$, each in autarky as described in Section 2 to those sharing the frontier technology as described in Section 3. Comparing the adoption and matching behavior in Setion 2 and that in Section 3, I have:

A. Growth to Growth

Country i, for any i, grows perpetually both in autarky and in the globalized world if a) $\phi \geq \bar{\phi}$; or b) $\check{\phi}_a \leq \phi \leq \bar{\phi}$; $n_1^i \in S_w^2$; $\{n_1^j\} \not\subset S_w^1$; and $\{n_1^j\} \not\subset S_w^3$.

B. Growth to Growth or Stagnation

Country i, for any i, grows perpetually both in autarky and in the globalized world, or grows perpetually in autarky but stagnates perpetually after at most two periods of growth in the globalized world if c) $\check{\phi}_a \leq \phi \leq \bar{\phi}$; $n_1^i \in S_a^2$; and $\{n_1^j\} \subset S_w^1$; or d) $\check{\phi}_a \leq \phi \leq \bar{\phi}$; $n_1^i \in S_a^2$; and $\{n_1^j\} \subset S_w^3$.

C. Stagnation to Growth

Country i, for any i, stagnates perpetually after at most two periods of growth in autarky but grows perpetually in the globalized world if e) $\check{\phi}_a \leq \phi \leq \bar{\phi}$; $n_1^i \in S_a^1 \cup S_a^3$; $\{n_1^j\} \not\subset S_w^1$; and $\{n_1^j\} \not\subset S_w^3$; or f) $\check{\phi}_w < \phi \leq \check{\phi}_a$; $\{n_1^j\} \not\subset S_w^1$; and $\{n_1^j\} \not\subset S_w^3$.

D. Stagnation to Growth or Stagnation

Country i, for any i, stagnates perpetually after at most two periods of growth both in autarky and in the globalized world, or stagnates perpetually after at most two periods of growth in autarky but grows perpetually in the globalized world if g) $\check{\phi}_a \leq \phi \leq \bar{\phi}$; $n_1^i \in S_a^1$; and $\{n_1^j\} \subset S_w^1$; h) $\check{\phi}_a \leq \phi \leq \bar{\phi}$; $n_1^i \in S_a^3$; and $\{n_1^j\} \subset S_w^3$; i) $\tilde{\phi}_w < \phi \leq \check{\phi}_a$; and $\{n_1^j\} \subset S_w^1$; or j) $\tilde{\phi}_w < \phi \leq \check{\phi}_a$; and $\{n_1^j\} \subset S_w^3$.

If $\phi < \tilde{\phi}_w$, every country stagnates eventually in autarky while there may be a perpetual growth in the globalized world depending on parameter values and the distribution of human capital across countries. A consequence is that economic integration will *not* turn a perpetual growth to a perpetual stagnation. I highlight the conditions for the stagnation-to-growth and the growth-to-stagnation transitions:

Proposition 3. Assume that $n_1 + n_2 = 1$ and $\tilde{\phi}_w < \phi \leq \bar{\phi}$. A sufficient condition for country i, for any i, to stagnate eventually in autarky but to grow perpetually in economic integration is $n_1^i \in S_a^1 \cup S_a^3$, $\{n_1^j\} \not\subset S_w^1$, and $\{n_1^j\} \not\subset S_w^3$. A necessary condition for country i, for any i, to grow perpetually in autarky but to stagnate eventually in economic integration is (a) $n_1^i \in S_w^1 \cap S_a^2$ and $\{n_1^j\} \subset S_w^1$; or (b) $n_1^i \in S_w^2 \cap S_a^3$ and $\{n_1^j\} \subset S_w^3$.

Proof: to be written.

The condition for the stagnation-to-growth transition combines the skewness of the human capital distribution of country i and the diversity of the human capital distribution among all countries. The condition for the growth-to-stagnation transition requires that the human capital distribution of a coutry is not skewed enough for a perpetual growth while it is skewed enough for a perpetual growth in economic integration. That such a disbribution of human capital exists underlines that the skewness necessary for a perpetual growth in economic integration is less severe than the skewness necessary for a perpetual growth in autarky. In order to gain intuition, consider a country in autarky, call it country A, and a country in economic integration, call it country B. Assume that the two countries have the human capital distribution, and suppose that both countries stagnate in equilibrium. If the young generation were to exercise the outside option of an all-out-technology-adoption, it would lead to a stagnaton in country A in the next period but it would lead to a growth in country B in the next period by triggering the growth in the other countries. In other words, country A would enjoy the stagnation premium but country B would not. Thus the reservation utility of the young generation is higher and the old generation's utility is lower in country A than in country B. Since the same situation is repeated every period in stagnation, the aggregate utility, i.e., the current output plus the discounted utility of the young generation's utility when they become old, is lower in country A than in country B. The best alternative to stagnation is to grow two periods and then stagnate in both country A and country B. There would be no stagnation premium in both countries in the next period. In fact, the aggregate utility of this alternative is the same between the countries. Therefore, in some range of human capital distribution the advantage of stagnation vanishes in country A while it remains in country B. Since the stagnation range of human capital distribution is smaller in autarky than in economic integration, the range where the stagnation follows a period of growth is smaller in autarky than in economic integration too.

Now consider the effect of economic integration on the aggregate utility. Assume that $\tilde{\phi}_w \leq \phi \leq \bar{\phi}$ and Unconditional Growth World Equilibirum 2 holds after economic integration. Again, Unconditional Growth World Equilibirum 2 is the unique equilibrium in the assumed range of parameter values if there is enough a diversity among countries. Further, note the fundamental asymmetry between the advancement and the stagnation of the frontier technology when there are multiple countries: it takes only one country to advance the technology while it takes all of the countries to hold the technology. Loosely speaking outside the current model, random factors can disrupt a stagnation more easily than a growth in a multi-country world. Let $\tilde{W}(n^i) \equiv \check{W}^i(n) = \check{W}^i(..., n^{i-1}, n^i, n^{i+1}, ...)$

under Unconditional Growth World Equilibirum 2. Note that $\tilde{W}(n^i)$ is independent of $\{n^j\}_{j\neq i}$. Let $\check{x}$ implicitly defined by $\hat{W}(n^i) \geq \tilde{W}(n^i)$ for all n^i with $n_1^i + n_2^i = 1$ and $n_1^i \in [\check{x}, 1]$. Similarly, let $\hat{x}$ implicitly defined by $\hat{W}(n^i) \geq \tilde{W}(n^i)$ all n^i with $n_1^i + n_2^i = 1$ and $n_1^i \in [0, \hat{x}]$. I can derive: $\check{x}$ is increasing in ϕ if $\tilde{\phi}_w \leq \phi \leq \bar{\phi}$; $\check{x} = 1$ when $\phi = \bar{\phi}$; and $\check{x} = \hat{x}$ when $\phi = \check{\phi}_3 \equiv (1 - \beta\mu + 2\beta\lambda\mu - \beta\lambda^2\mu - \beta^2\lambda\mu^2)/((1-\beta)(1-\beta\mu+\beta\lambda\mu) + \beta\lambda^2(1-\mu) + \beta\lambda\mu(1-\beta\mu)(1-\beta+\beta\lambda))$; $\hat{x} = \beta^2\lambda\mu^2/(1-\beta\mu+\beta\lambda\mu)$ if $\hat{\phi} \leq \phi \leq \bar{\phi}$; $\hat{x}$ is increasing in ϕ if $\tilde{\phi}_w \leq \phi \leq \hat{\phi}$; and $\hat{x} = \check{x}$ when $\phi = \check{\phi}_3$. Let $S_u^1 \equiv [0, \hat{x})$; $S_u^2 \equiv (\hat{x}, \check{x})$; and $S_u^3 \equiv (\check{x}, 1]$. In summary, I have:

Proposition 4. Assume that $\tilde{\phi}_w \leq \phi \leq \bar{\phi}$ and Unconditional Growth World Equilibirum 2 holds in economic integration. Economic integration raises the aggregate utility of country i, for any i, if $n_1^i \in S_u^2$. Economic integration lowers the aggregate utility of country i, for any i, if $n_1^i \in S_u^1 \cup S_u^3$.

Proof: to be written.

I can show that $S_u^2 \supset S_a^2$. This implies that if economic integration lowers the aggregate utility, the country would have stagnated in autarky. In other words, economic integration eliminates the option to hold the frontier technology and to enjoy the stagnation premium. Loosely speaking, the current generations of the country would prefer to isolate itself from the world permanently. However, this is not feasible assuming that the rest of the world will continue to grow: the advantage of adopting the frontier technology would eventually outweigh the loss of the stagnation premium.

4.2 Political Integration

Now consider the transition of a globalized but politically fragmented world as described in Section 3 to a single political union as described in Section 2. The distribution of human capital in the union is:

$$n^u = \sum_i \eta^i n^i \tag{18}$$

where η^i is country i's share of the world population: $\sum_i \eta^i = 1$. The characterization of transition is equivalent to that in Section 4.1 except that the change is in the opposite direction and country i is replaced by political union u. Similarly, if $\phi < \tilde{\phi}_w$, there may be a perpetual growth in the globalized world depending on parameter values and the distribution of human capital across countries while the political union stagnates. A consequence is that political integration will *not* turn a perpetual stagnation to a perpetual growth. I highlight the conditions for the growth-to-stagnation and the stagnation-to-growth transitions:

Proposition 5. Assume that $n_1 + n_2 = 1$ and $\tilde{\phi}_w < \phi \leq \bar{\phi}$. A sufficient condition for the world economy to grow perpetually in political fragmentation but to stagnate eventually in political union is $n_1^u \in S_a^1 \cup S_a^3$, $\{n_1^j\} \not\subset S_w^1$, and $\{n_1^j\} \not\subset S_w^3$. A necessary condition for the world economy to stagnate eventually in political fragmentation but to grow perpetually in political union is (a) $n_1^u \in S_w^1 \cap S_a^2$ and $\{n_1^j\} \subset S_w^1$; or (b) $n_1^u \in S_w^2 \cap S_a^3$ and $\{n_1^j\} \subset S_w^3$.

Proof: to be written.

Consider a once-and-for-all formation of political union. Assume that $\tilde{\phi}_w \leq \phi \leq \bar{\phi}$ and Unconditional Growth World Equilibirum 2 holds in political fragmentation as in Section 4.1. I can show that $\tilde{W}(n^i)$ is linear in n^i so that:

$$\sum_i \eta^i \tilde{W}(n^i) = \tilde{W}\left(\sum_i \eta^i n^i\right) = \tilde{W}\left(n^u\right) \tag{19}$$

for all $\{\eta^i\}$ and $\{n^i\}$. Thus the utility comparison of a politically fragmented world and a political union is analogous to the utility comparison of a country in the autarky and a country in economic integration in Section 4.1:

Proposition 6. Assume that $\tilde{\phi}_w \leq \phi \leq \bar{\phi}$ and Unconditional Growth World Equilibirum 2 holds in political fragmentation. Political integration raises the worldwide aggregate utility if $n_1^u \in S_u^1 \cup S_u^3$. Political integration lowers the worldwide aggregate utility if $n_1^u \in S_u^2$.

Proof: to be written.

Now suppose that the opportunity to form or break up a political union is a small probability event in every period so that the utility comparison can be done as if the formation or the break-up is permanent in approximation. Assume efficiency in the cross-country bargaining: the bargaining outcome maximizes the worldwide aggregate utility of the current generations. According to proposition 6, the political union would form if and only if $n_1^u \in S_u^1 \cup S_u^3$. Let $\tilde{S}_u^1 \equiv (0, \max\{\hat{x}, 1 - \check{x}\})$; $\tilde{S}_u^2 \equiv (\max\{\hat{x}, 1 - \check{x}\}, \min\{\check{x}, 1 - \hat{x}\})$; and $\tilde{S}_u^3 \equiv (\min\{\check{x}, 1 - \hat{x}\}, 1)$. Applying the equilibirum adoption and matching behavior, I can show that the political union will form eventually if and only if $n_1^u \in \tilde{S}_u^1 \cup \tilde{S}_u^3$. Let $\xi^0(n^i) = n^i$ and $\xi^{t+1}(n^i) \equiv \Lambda n(1, g(1, \xi^t(n^i)))$ where g is the equilibirum adoption and matching behavior in Section 2. I can show that if $n_1^u \in S_u^1 \cup S_u^3$, $\xi^t(n_1^u) \in S_u^3$ for all $t \geq 1$. In words, the political union will stagnate after at most one period of growth unless there is a break-up. Further, from proposition 6, I have $\hat{W}(\xi^t(n^u)) \geq \tilde{W}(\xi^t(n^u))$ for all t. Combined with (19), I have:

$$\hat{W}(\xi^t(n^u)) \geq \sum\nolimits_i \tilde{\eta}_t^i \tilde{W}(m_t^i) \tag{20}$$

for all t and for any $\{\tilde{\eta}_t^i\}$ and $\{m_t^i\}$ that satisfy $\xi^t(n^u) = \sum_i \tilde{\eta}_t^i m_t^i$. Thus there is no incentive to break up a political union once it is formed. Now let $\tilde{g}^i(h_0, n) \equiv g^i(h_0, n) = g^i(h_0, (..., n^{i-1}, n^i, n^{i+1}, ...))$ where g^i is the equilibirum adoption and matching behavior under Unconditional Growth World Equilibirum 2 in Section 3. Note that $\tilde{g}^i(h_0, n)$ is independent of $\{n^j\}_{j \neq i}$. Let $\tilde{\xi}^0(n^i) \equiv n^i$ and $\tilde{\xi}^{t+1}(n^i) \equiv \Lambda n^i(1, \tilde{g}^i(1, \tilde{\xi}^t(n^i)))$. Reasoning as above, I have:

$$\hat{W}\left(\sum\nolimits_i \eta^i \tilde{\xi}^t(n^i)\right) \leq \sum\nolimits_i \eta^i \tilde{W}\left(\tilde{\xi}^t(n^i)\right) \tag{21}$$

for all t if $n_1^u \in S_u^2$. Thus, under this condition there will never be an incentive to form a political union. In summary, I have:

Proposition 7. Assume that $\tilde{\phi}_w \leq \phi \leq \bar{\phi}$ and Unconditional Growth World Equilibirum 2 holds in political fragmentation. The political union will form eventually if $n_1^u \in \tilde{S}_u^1 \cup \tilde{S}_u^3$. Once formed, the politcal union will stagnate after at most one period of growth and it will never break-up. The world economy will always remain politically fragmented and grow perpetually if $n_1^u \in \tilde{S}_u^2$.

Proof: to be written.

5. Conclusion

In summary, the economically integrated but politically fragmented world is the most conducive to a long-run growth while an economy in autarky or a political union is more likely to stagnate. Consequently, economic integration (i.e., sharing of the frontier technology among countries) promotes growth while political integration (i.e., merging of countries into a single bargaining) promotes stagnation. Since a political union is an economy in autarky, political integration is essentially a reverse of economic integration. The implicit asymmetry is that economic integration is exogenous to a country while political integration is a collective choice by all countries.

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