

NBER WORKING PAPER SERIES

HUMAN CAPITAL AS ENGINE OF GROWTH – THE ROLE OF KNOWLEDGE  
TRANSFERS IN PROMOTING BALANCED GROWTH WITHIN AND ACROSS  
COUNTRIES

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Working Paper 26810  
<http://www.nber.org/papers/w26810>

NATIONAL BUREAU OF ECONOMIC RESEARCH  
1050 Massachusetts Avenue  
Cambridge, MA 02138  
February 2020

This paper is based on lectures given at the Asian Development Bank's Distinguished Speakers Program in Manila on August 2, 2019 and the Conference on Human Capital and Economic Development in China, sponsored by the Center for Excellence on Human Capital, Technology Transfer, and Economic Growth and Development, and the Confucius Institute at the University at Buffalo on October 5, 2019. The authors are indebted to Yasuyuki Sawada for very helpful comments on a previous draft and to Sungmin Park for dedicated assistance. The first author acknowledges the financial support from the Asian Development Bank for his lecture and paper. The usual ADB disclaimer applies. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

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Human Capital as Engine of Growth – The Role of Knowledge Transfers in Promoting Balanced Growth Within and Across Countries

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NBER Working Paper No. 26810

February 2020

JEL No. F22,F43,J11,J24,O15

**ABSTRACT**

Unlike physical capital, human capital has both embodied and disembodied dimensions. It can be perceived of as skill and acquired knowledge, but also as knowledge spillover effects between overlapping generations and across different skill groups within and across countries. We illustrate the roles these characteristics play in the process of economic development; the relation between income growth and income and fertility distributions; and the relevance of human capital in determining the skill distribution of immigrants in a balanced-growth global equilibrium setting. In all three illustrations, knowledge spillover effects play a key role. The analysis offers new insights for understanding the decline in fertility below population replacement rate in many developed countries; the evolution of income and fertility distributions across developing and developed countries; and the often asymmetric effects that endogenous immigration flows and their skill composition exert on the long-term net benefits from immigration to natives in source and destination countries.

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## **I. Introduction**

In this paper we focus on an underlying aspect of human capital as engine of growth – the role of knowledge transfers – which has received only a modest attention in the literature so far. To introduce the subject matter, we start with an attempted definition of human capital, its distinct characteristics, and its relevance for the process of economic growth and development as well as the demographic changes that appear to accompany this process.

Human capital is “an intangible asset, best thought of as a stock of embodied and disembodied knowledge, comprising education, information, health, entrepreneurship, and productive and innovative skills, that is formed through investments in schooling, job training, and health, as well as through research and development projects and informal knowledge transfers” (Ehrlich and Murphy, 2007). It is considered a “capital” asset because of its enduring impact on the returns to knowledge. In this context, it resembles physical capital as well. Both capital assets are subject to depreciation and obsolescence. And, like physical capital, human capital can also be formed through investment. However, there are also important differences between the two. We count 5 major distinctions:

First, human capital is embodied in people. So unlike physical capital, it is controlled by individuals with heterogeneous abilities and preferences who choose how and where to employ it – in different occupations, markets, non-market activities, or even countries in the case of international migration.

Second, being embodied in people, human capital formation cannot be separated from population formation, by which we mean decisions about family formation, fertility, health, and longevity.

Third, unlike physical capital, human capital has limited opportunities to be monetized as a stock, and cannot serve as a collateral, which imposes financing constraints on investment in its formation.

Fourth, unlike physical capital, human capital has both embodied and disembodied dimensions. It can be manifested as personal knowledge or skill acquired via schooling, training, and R&D, but also via *knowledge spillover effects* arising from publicly accessible books and articles, interaction between people, and informal means of communication. Extant human capital can thus be productive in creating new human capital, as well as social capital by forming networks

of people. Unlike physical capital, disembodied human capital is thus also likely to generate positive externalities.

Finally, because of its latter distinct property, we believe that John Maurice Clark (1923) was right in proposing that human capital, or knowledge, as he put it, is the only instrument of production that is not subject to diminishing returns.

We consider the last two characteristics of human capital to be a key for understanding its critical role in determining the level and distribution of per-capita income within and across countries at a point in time, as well as income growth and income distribution within and across countries over the long haul. We illustrate and defend this argument using three selected topics that are based on our previous and current research, as we point out in the introduction to each of the following sections. They include:

The process of development – the shift from a stationary state, or “stagnant” economic development regime to a persistent growth regime. In this section, we show that an exogenous shock, such as a technological advance in health maintenance that raises sufficiently the life expectancy of children, can increase the incentive of parents to make sufficient investments in the human capital of their children that can trigger a takeoff to persistent and self-sustaining growth. The underlying reason is that the disembodied human capital level accumulated by the parents’ generation and the knowledge spillover effects they generate, running from parents to their offspring’s generation, are not subject to diminishing returns.

The relation between income growth and income and fertility inequality in a balanced-growth, closed economy setting. In this section, disembodied human capital and its spillover effects across different skill groups can explain the link between per-capita income growth and income distribution over the transition from stagnant, or lower-growth equilibrium to a higher and persistent growth equilibrium.

The relevance of human capital in explaining the net benefits from immigration in a balanced growth, global equilibrium setting. In this section, disembodied human capital and its spillover effects can explain the long-term consequences of immigration on per-capita income growth and income distribution across countries.

In each of these sections we use an endogenous growth and development framework in which human capital is the engine, or basic driver, of growth, and knowledge spillover effects are essential for establishing the existence of balanced growth equilibrium solutions. This framework

enables us to derive the long-term effects of shifts in external triggers and underlying exogenous factors which affect the equilibrium solutions via the relevant comparative dynamics analysis, and evaluate their impact on the rate and direction of long-term income growth, income distribution, and demographic changes within and across countries. It also enables us to assess their welfare implications and some of their policy ramifications.

## **II. Human Capital and Long-Term Economic Development**

### **A. From Sporadic to Perpetual Economic Growth**

The story of “growth” in many Western countries, which can be characterized as persistent, self-sustaining growth in per-capita income, has been in existence for about 150-200 years following the first industrial revolution, after being more or less stagnant during the Middle Ages. The transition from stagnation to growth is one way to think about the historical pattern: what can trigger such shift? And what is the underlying engine of growth that could explain not just the shift from a low level of development into persistent growth in per-capita income, but also the demographic transition that has accompanied such a growth pattern in many other parts of the world in more recent decades?

The neoclassical growth model mitigated the Malthusian population explosion threat by showing how it could be balanced by a commensurate growth in physical capital that can produce a constant level of per-capita income. But that model cannot assure growth in per-capita income under an exogenously given and constant technology.

This issue has been taken up by the endogenous growth literature, which recognizes human capital as the “engine” or driver of growth that assures continuous productivity growth.<sup>1</sup> There are alternative stories to explain endogenous growth through persisting R&D investments (such as Romer, 1990), but one important reason to consider the human capital story is that it can also explain the “demographic transition” – rising longevity and declining fertility, which is seen to be an inseparable part of the endogenous growth story.

In this section, we describe a model of endogenous growth where human capital is the

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<sup>1</sup> In this section we rely primarily on Ehrlich (1990), and Ehrlich and Lui (1991, 1998) as well as, indirectly, on the seminal human-capital based approach to endogenous growth by Lucas (1988) and Becker, Murphy and Tamura (1990).

only instrument of production and its knowledge spillover effects serve as both the engine of growth and the source of the demographic transition. The model is drawn from Ehrlich and Lui (1991).

## B. Human Capital Formation Process

In discrete time the human capital production process can be described as a function of parental inputs augmented by parental transferrable knowledge and a transmission technology, as follows:

$$H_{t+1} = A(H_t + H_0)h_t, \quad (1)$$

where  $H_{t+1}$  denotes the human capital level of an offspring,  $A$  denotes the knowledge transmission technology,  $H_t + H_0$  represent the parent's (generation) production capacity, consisting of raw labor ( $H_0$ ) and the parent's stock of human capital ( $H_t$ ), and  $h_t$  denotes the share of the production capacity allocated to building knowledge in the offspring.

Equation (1) formalizes the assumption that human capital is not subject to diminishing returns since under any given transmission technology ( $A$ ) and investment level ( $h$ ) there is a linear relation between parents' accumulated knowledge and what is transmitted to children via parental knowledge spillover effects. This is a necessary condition for human capital accumulation.<sup>2</sup>

Since human capital is the only capital asset in the economy, with a unitary rental cost, and labor time is normalized at 1, representing all time available for both market and non-market production, the growth rate of the offspring's potential income is given by

$$[(H_{t+1} + H_0)/(H_t + H_0)] \equiv (1 + g_t) = Ah^*, \text{ as } H_t \rightarrow \infty. \quad (2)$$

Persistent growth rate in potential income (production capacity),  $(1+g)$ , can thus be positive if, and only if,  $Ah^* > 1$ . If  $Ah^* \leq 1$ , the economy will converge on a stagnant-equilibrium level of development.

The implication of this analysis is that for an economy to move from a state of "stagnation" or periodic growth, to a state of endogenous growth, i.e., self-sustaining, persistent growth, it is necessary for the economy to invest a sufficiently high proportion of its production capacity in

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<sup>2</sup> Lucas (1988) also incorporates spillover effects in his model, coming from the average agent, but this is neither a necessary nor a sufficient condition for deriving a growth equilibrium in that model, which is based on an infinitely lived agent.

human capital formation.

The sufficient investment rate must exceed  $(1/A)$ . Note that this requires a larger share of productive capacity to be allocated toward human capital investments in the least developed countries, where the technology level,  $A$ , is well below that in the developed countries, which may be a major reason why many of these countries remain in a stagnant equilibrium trap.

### **C. Endogenous Growth and the Demographic Transition**

By this approach, whether the economy is in a stagnant or a growth regime depends on the principal objectives motivating parents (or their representative government) to invest in their children, as well as on external shocks that can bring about a significant change in these incentives. The study by Ehrlich and Lui (1991), for example, recognizes two major motivating forces benefitting parents:

The first is old age support, which can also be thought of as family insurance or intergenerational trade.

The second is altruism, or companionship: parents enjoy vicariously both the number of children they have as well as the quality of the children – the human capital or potential income they help produce in their offspring.

These motives increase the demand for both the number and quality of children. Whether parents can receive any of these benefits, however, depends on the children's probability of survival, or life expectancy.

Another important feature of the human-capital-based endogenous growth paradigm is that it can explain the “demographic transition”, which invariably accompanies a transition from stagnation or a low level of “development” to self-sustaining “growth”. This sets the model apart from Lucas (1988), where the agent is infinitely lived, and Romer (1990), where human capital is exogenous, so there is never any demographic transition.

### **D. Model Setup**

The decision maker is a representative agent – a young parent in an extended-family setup – where young parents bear and raise children and provide old-age support to their elderly parents.

Specifically, agents live through 3 periods: from childhood to adulthood, with survival probability  $\pi_1$ , and from adulthood to old age, with probability  $\pi_2$ . The unit costs to young parents of raising children ( $n_t$ ) and investing in their human capital are  $v$  and  $h_t$ , respectively. The extended family is assumed to be self-insured against the prospects of non-survival of children to adulthood and of non-survival of adults to old age. Specifically old parents receive compensations from their surviving adult children ( $\pi_1 n_t$ ) at a rate  $\omega_{t+1}$  that is proportional to the children's attained human capital ( $H_{t+1}$ ), so an old parent receives old-age material benefit in the amount  $\pi_1 n_t \omega_{t+1} H_{t+1}$ . Each adult child, in turn, pays a premium to the family insurance pool that is adjusted by the old parent's probability of survival,  $\pi_2 \omega_t H_t$ . Parents are also altruistic toward their children and derive psychic benefits, or “companionship” from the expected number of children surviving to adulthood and the human capital stock they helped build in each child.<sup>3</sup>

Under the extended family insurance setup, the representative adult's consumption flow at adulthood (period  $t$ ) is thus given by

$$C_t^1 = (H_t + H_0)(1 - vn_t - h_t n_t) - \pi_2 \omega_t H_t. \quad (3)$$

The expected consumption flow parents derive at old age, funded by the earnings of the expected number of surviving offspring, is given by

$$C_{t+1}^2 = \pi_1 n_t \omega_{t+1} H_{t+1}, \quad (4)$$

and the expected altruistic benefits ( $W$ ) the old parents derive from their surviving offspring is given by

$$W_{t+1} = B(\pi_1 n_t)^\beta (H_{t+1})^\alpha, \quad (5)$$

where  $B$  is an altruism, or “companionship” parameter, as termed in Ehrlich and Lui (1991). The expected life time utility function which the parent maximizes by choosing optimal values of fertility and investment in human capital is thus

$$U_t^* = [1/(1 - \sigma)][(C_t^1)^{1-\sigma} - 1] + \delta \pi_2 [1/(1 - \sigma)][(C_{t+1}^2)^{1-\sigma} - 1] + [(W_{t+1})^{1-\sigma} - 1], \quad (6)$$

where  $\sigma < 1$  is the inverse value of the elasticity of substitution in consumption and  $0 < \delta < 1$  is a generational discount factor. The representative parent is then maximizing this expected life-time utility function with respect to fertility and investment in human capital, and thus the consumption flows at young and old age, subject to the budget constraints specified in equations

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<sup>3</sup> Although the probabilities of survival  $\pi_1$  and  $\pi_2$  are in principle endogenously determined by parental investments in their own, and children's health (see Ehrlich and Kim, 2005, and Ehrlich and Yin, 2013), in this analysis they are treated as functions of the exogenously given state of the arts in medical science.



(3) and (4) and the conditions assuring the concavity of equation (6). The latter is satisfied subject to the following parametric restrictions,

$$1/(1 - \sigma) > \beta > \alpha \text{ and } 1 \geq \alpha. \quad (7)$$

To assure that the choice variables have interior solutions, it is necessary that the elasticity of substitution in consumption,  $\sigma < 1$  is large enough to exceed the elasticities of the marginal psychic returns to the quantity of children ( $\beta$ ) and that the latter would exceed the elasticity of the marginal psychic return to the “quality” of children ( $\alpha$ ). This is because the assumed egalitarian treatment of all children by altruistic parents implies that the opportunity cost of having another child accounts for the desire to provide that child the same educational opportunities as those given to her siblings.

### **E. Endogenous Growth and the Demographic Transition**

By integrating these elements of an endogenous growth model and solving the dynamic maximization problem, it can be shown that an upward shock in the life expectancy of children ( $\pi_1$ ) due to technological breakthroughs in health science, like sanitation or pasteurization of milk, can trigger a takeoff from stagnant to growth equilibrium by raising  $h^*$  sufficiently, so that the growth rate of human capital ( $1 + g$ ) exceeds 1 (i.e.,  $Ah > 1$ ). Put differently, a growth equilibrium is possible if, and only if, investment in human capital as a fraction of parental production capacity or potential income exceeds a critical value  $h^* > 1/A$ . The model suggests that this outcome can be facilitated by a technological shock that sufficiently raises life expectancy, since a higher level of the latter raises one’s potential lifetime earnings and thus the expected return on investment in human capital.

Initially both investment in children’s human capital and fertility go up because of the wealth effect generated by the shock. But as incomes go up, the net altruistic benefits of having more children starts declining because the opportunity costs of having a larger number of children rise relative to the option of having less children, but more educated ones. Put differently, a substitution effect from “quantity” toward “quality” of children emerges, which can reduce fertility quite sharply. In the Ehrlich-Lui (1991) model, this substitution effect is further reinforced by the family-security system whereby children provide old-age support for their old parents. The paper shows that this old-age support motive can be served more efficiently (i.e., at a lower cost to

parents) by having less children but investing more in their human capital.

The following charts simulate these results. In Figure 1, a sufficiently large upward shock in  $\pi_1$  (the probability of survival from childhood to adulthood) can raise the level and slope of the stagnant equilibrium path of human capital formation (I) from its stagnant equilibrium regime (point A on the 45 degree line) into a path of perpetual growth equilibrium regime (II). Figure 2 illustrates how this shift to perpetual growth affects the underlying time paths of fertility and investment in human capital.<sup>4</sup> While investment in human capital rises sharply in absolute value, fertility declines continuously to the point where even a “corner solution” might arise. Technically, this corner solution occurs only if the elasticity of marginal preference for “quality”, as reflected in the level of human capital attained by offspring, is less than 1 (i.e., if  $\alpha < 1$ ).<sup>5</sup> This constrained parameter implies that over time the marginal psychic net benefits from having children turns negative, which justifies a corner solution. Figure 2 illustrates this solution by restricting the value of fertility ( $n$ ) to reach an arbitrarily small positive level (so countries do not disappear). A more realistic restriction is  $\alpha = 1$ , in which case, optimal fertility is always an interior solution and can reach a level below population-replacement level.

[Insert Figure 1]

[Insert Figure 2]

These results were considered to be harsh results in 1991 when total fertility rates (TFR) in the most developed economies were above “replacement levels” (a TFR above 2.1 per family). But today we have 80 countries out of 200 comprising the oldest countries in the world where TFR is below 2. See Figures 3, 4 and 5.

[Insert Figure 3]

[Insert Figure 4]

[Insert Figure 5]

What is notable about these figures is that in both the highly developed Western countries – the United States (the U.S.) and the United Kingdom (the U.K.), where takeoff to growth started

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<sup>4</sup> The parameters used to simulate Figures 1 and 2 are:  $A = 5.5$ ;  $v = 0.13$ ;  $\alpha = 0$ ;  $\beta = 0.75$ ;  $\sigma = 0.5$ ;  $\pi_1 = 0.6$ ;  $\pi_2 = 0.6$ ;  $\omega = 0.45$ ;  $H_0 = 0.5$ . The stationary equilibrium at point A produces optimal values of  $H^* = 0.292$  and  $n^* = 2.793$ . A technological innovation shifting the value of  $\pi_1$  from 0.6 to 1 lifts the dynamic path I to II where  $H^*$  grows without bound while  $n^*$  in Figure 2 falls to a corner solution set arbitrarily at  $n^* = 1$ .

<sup>5</sup> In Figure 2, the declining fertility per family path ends arbitrarily at a rate of 1. An alternative explanation for the decline in fertility below the replacement level is provided in Ehrlich and Kim (2007a) where fertility is modeled as a decision variable that is determined jointly with a family formation decision. Fertility trends are shown to be the results of declining trends in the share of married, relative to single households, as well as in fertility within these families.

in the early 19<sup>th</sup> century, and in the fast-developing Asian countries, where takeoff to growth started in the early 1960s, the evolution pattern of fertility – an initial rise followed by a continuing and persistent decline - tend to be mirror images, as they occur around the same time period in which the respective economies start taking off from a relatively stagnant equilibrium regime toward a regime of a self-sustaining growth. And like some South European countries, the developing countries in East Asia and the Pacific exhibit fertility levels that are below those in the most developed Western countries (the U.S. and the U.K.), as shown in Figures 3 and 4. One reason for this result is that the old-age support motive has traditionally played a stronger role in Asian culture where the family-security system has been an important channel for providing old-age support before the more recent establishment of a public social security system. This is consistent with the implications of the family-security model addressed in this section which accentuates the substitution of quantity for quality of children (see Figure 5). Another factor is that the more developed Western countries attract a higher share of immigrants coming from sending countries with high fertility rates, which offsets to some extent the declining fertility rates in the immigration-receiving countries, whereas in the Asian countries immigration rates have remained relatively low. This point will be further developed in Section IV of this paper.

#### **F. From Positive to Higher Growth – the U.S. Ascendancy as Economic Superpower**

Another example of a shock that started a new takeoff from a relatively low growth equilibrium to a higher and persistent long-term growth regime is the Morrill Act of 1862 in the U.S. that established for the first time – to our knowledge anywhere in the world – a public higher education system. The act led to the formation of the Land Grant university system, which established most of the major leading public universities in the U.S. (for example, Berkeley, UCLA, Penn and Michigan State). Unlike the takeoff from a stagnant to a growth equilibrium we discussed in the previous subsection, which was simulated from a theoretical model where the trigger was assumed to be an upward shock in the probability of survival from childhood to adulthood, the trigger implicit in the Morrill Act was the significant reduction in the financing costs of college education. The land grants made enrollment in higher education possible for all students, especially those from low and middle-income families, who could not previously afford the prohibitive tuition costs of higher education in the few exclusive older private colleges in the U.S. that were

accessible primarily to students from wealthy families. A recent paper by Ehrlich, Cook and Yin (2018) has developed and applied empirically a Lucas-type endogenous growth model of institutional change indicating that this act may have been a major factor that promoted the rate of growth of the U.S. in the latter part of the 19<sup>th</sup> century, and enabled the U.S. to overtake the U.K. as an economic superpower in the 20<sup>th</sup> century. The U.K. lagged 50 years behind the U.S. in launching a comparable system of public universities.

### **III. Income Growth and Income Distribution<sup>6</sup>**

#### **A. Linking Income Growth and Income and Fertility Distribution**

The homogeneous-agent, human-capital-based endogenous growth model generates important and testable implications about intergenerational knowledge transfer, the transitional development phase, and the demographic transition, leading to a balanced growth in per-capita income. But the model is silent about how the distribution of income evolves over this transitional phase. This issue has been of major interest in the more traditional development literature. In particular, Kuznets (1955, 1963) proposed his “inverted-U curve” hypothesis to characterize the behavior of income inequality in the transition from a lower to a higher development stage. The ensuing literature, however, has offered conflicting evidence and inference about the Kuznets’ hypothesis and the direction of causality between income growth and income inequality.

Any model dealing with the income distribution issue must start with a recognition of the sources of income diversity and why they vary over the development process. While there is a vast literature dealing with this topic, a major void in this literature is that it has largely overlooked the endogeneity of not just the level and the distribution of income, but also the level and distribution of demographic variables over the transition from a stagnant, or low development level to an endogenous growth equilibrium regime. This is especially important when the Gini coefficient is used as an inequality measure, since it is a function of both family income inequality and the distribution of families across income brackets. The latter depends on the distribution of the relative family group sizes and hence the fertility rates across different family groups.

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<sup>6</sup> This section draws largely from Ehrlich and Kim (2007). See also, Kuznets (1955, 1963), Tamura (1991), Zhong (1998), and De la Croix and Doepke (2003).

Following Ehrlich and Kim (2007), we take a holistic approach to deal with this latter issue, by attempting to explain income growth and income distribution as endogenous outcomes of a paradigm that allows for heterogeneity across individuals or family groups, and accounts for what separates these groups as well as what links them together. Human capital remains the engine of growth and the sole instrument of production in this model, while labor time is normalized at 1, as in Section II. However, we here assume the existence of different “skill groups” due to differences in their inherited ability and family background. We recognize three sources of inherent heterogeneity: (i) differences in learning or production abilities ( $A^i$ ); (ii) differences in income-yielding “endowments” ( $H_0^i$ ) stemming from inherited social status, or wealth; and (iii) differences in education-financing costs ( $\theta^i$ ). The latter can be affected by government educational policies that enable the introduction of social mobility in the model. We abstract from differences in preferences or external production technologies, since these need not be related to idiosyncratic personal differences.

The inherited sources of family differences are what separates the agents in the model. What links them, however, are knowledge spillover effects across different skill groups. The role of spillover effects from disembodied human capital thus becomes a central focus of this section.

## **B. Basic Elements of the Model**

To recognize inherent heterogeneities in the population, we assume for analytical simplicity that the population is composed of two family types with varying skills, or earning capacities ( $i = 1, 2$ ) due to positive assortative mating. Family group 1 is identified as the higher (initial) skill or leading group, while group 2 is the (initial) lower-skill, or follower group. Specifically, the two skill groups differ in ability ( $A^i$ ), family endowments ( $H_0^i$ ), and unit cost of investment in human capital as a fraction of potential income ( $\theta^i$ ), but share same personal and altruistic preferences. In addition, we also restrict the unit cost of rearing and raising offspring as a fraction of potential income to be uniformly distributed among all agents to enable a stable solution to the model, so  $v^i = v$ . As in the model presented in the previous section, human capital is the only productive capital asset in the economy. In this heterogeneous-agents model, however, we abstract from any uncertainty of survival from childhood to adulthood and assume that agents’ lifespan includes just two effective periods: childhood and adulthood, so all agents live through

these two periods. We further abstract from any need for old age support, although the introduction of savings in the model would not affect any of its qualitative implications. For analytical simplicity, we also assume that altruism is the only motive for having children.

The central assumption in the model is that while the human capital production function of the top skill group ( $i = 1$ ) remains the same as that specified in equation (1), the corresponding production function for the lower skill group ( $i = 2$ ) is augmented by the social interaction term  $(S_t^2)^\gamma$  reflecting the hierarchical *knowledge spillover effects* ( $S_t^2$ ) coming from the more knowledgeable skill group 1:

$$\begin{aligned} H_{t+1}^2 &= A^2 h_t^2 (H_0^2 + H_t^2)^{1-\gamma} [(H_0^1 + H_t^1)(N_t^1/N_t^i)]^\gamma \\ &\equiv A^2 h_t^2 (H_0^2 + H_t^2)(E_t^2 P_t^2)^\gamma \equiv A^2 h_t^2 (H_0^2 + H_t^2)(S_t^2)^\gamma. \end{aligned} \quad (8)$$

In equation (8)  $h_t^i$  measures investment rate per child as a fraction of the parent's earnings capacity;  $E_t^2 \equiv (H_0^1 + H_t^1)/(H_0^2 + H_t^2)$  measures relative production capacity and thus potential “family income inequality”;  $P_t^2 \equiv N_t^1/N_t^2$  denotes the relative income-group size in the population;  $N_t^i$  stands for the number of workers in the skill group  $i$ ;  $S_t^2 \equiv E_t^2 P_t^2$  is a measure of the knowledge spillover effect, and  $\gamma < 1$  indicates the latter's intensity.

The production function (8) expresses the role of two types of spillover effects or social interactions in production. The first is within families – human capital formation crucially depends on parental inputs, or transfer of knowledge from parents to children. The other is across families or skill groups indicating the knowledge transmission or learning is also a social process. The rationale behind  $S_t^2 \equiv E_t^2 P_t^2$  serving as a spillover of knowledge from high- to low-skill groups is that its first term,  $E_t^2 \equiv (H_0^1 + H_t^1)/(H_0^2 + H_t^2)$ , measuring the relative earnings capacity of the two, also indicates the relative gap in knowledge between the two groups and thus the potential gain to skill group 2 from its social interaction with group 1, while the second term  $P_t^2 \equiv N_t^1/N_t^2$  is a proxy for the odds of personal interaction between individual members of these skill groups, which is proportional to their respective population sizes. An alternative interpretation is that  $P_t^2$  captures the interaction intensity, as it represents the ratio of “teachers” (leaders) to “students” (followers), assuming that agents of type 1 are the effective source of knowledge transfer.

Note that  $E_t^2$  is a measure of “family-income inequality”, while  $S_t^2 \equiv E_t^2 P_t^2$  is a measure of “income-group” or “income-class” inequality, since  $P_t^2 \equiv N_t^1/N_t^2$  represents the share of the total population ( $N$ ) concentrated at the top relative to the bottom income brackets. A

third measure of inequality used in the model is the Gini coefficient. In a population comprised of just two income groups the Gini coefficient becomes  $G_t \equiv (S_t^2 - P_t^2)/[(1 + S_t^2)(1 + P_t^2)]$ , which is monotonically rising with  $S_t^2$  and falling with  $P_t^2$ .

### C. Objective Function and Optimization

The representative family heads ( $i = 1, 2$ ) in this model maximize their lifetime utility comprised of the utility from their own life-time consumption as well as the altruistic benefits they are assumed to derive from their offspring's potential lifetime income (production capacity):

$$U(C_t^i, W_{t+1}^i) = [1/(1 - \sigma)] [(C_t^i)^{1-\sigma} - 1] + \delta [1/(1 - \sigma)] [(W_{t+1}^i)^{1-\sigma} - 1], \quad (9)$$

with respect  $h_t$  and  $n_t$ , where

$$C_t^i = (H_0^i + H_t^i)(1 - v^i n_t^i - \theta^i h_t^i n_t^i), \quad (10)$$

is the parent's own lifetime consumption benefits at adulthood (period 1), and

$$W_{t+1}^i \equiv B(n_t^i)^\beta (H_0^i + H_{t+1}^i)^\alpha, \text{ with } \beta > \alpha \text{ and } \alpha = 1, \quad (11)$$

is the parent's altruistic benefits from having children. Note that equation (11) is similar to the altruism function (5) in Section II, with two exceptions: the psychic benefits from offspring's well-being are specified as a function of the latter's potential income, rather than just their human capital attainments, since this specification can be shown to allow for the existence of equilibrium under both stagnant and growth regimes. Also the restriction  $\alpha = 1$  is made in order to guarantee interior solutions in fertility, which are necessary to preserve heterogeneity in the model. As in equation (3),  $v^i$  and  $h^i$  are fractions of the parent  $i$ 's production capacity that are spent on raising and investing in the human capital of each child; and  $\theta^i$  is the unit cost of financing educational investment per child. Savings can be added as a separate choice variable so that earnings may stand for income.

Solving the first-order conditions we can obtain optimal interior solutions for fertility,  $n^i$ , and human capital investments,  $h^i$ , over two possible stable equilibrium regimes and a transition path connecting the two. Stability is guaranteed by the force of the knowledge spillover effects term,  $S_t^2$ , and the parameter restrictions assumed in this model:

$$1/(1 - \sigma) > \beta > \alpha = 1. \quad (12)$$

## D. Equilibrium Regimes<sup>7</sup>

Recall that human capital is the sole productive asset in this model, and time at work is normalized at 1 to reflect potential income in both market and non-market activities. In this case, equilibrium depends on the way human capital evolves over the generations. Equations (10) and (11) represent a recursive model, since the leading group 1 arrives at all of its choices independently as a function of its own parameters, while the following group 2's fertility choices are affected by those of family 1 through the social interaction term,  $(S_t^2)^\nu$ . From the human capital formation function and the optimal investment condition for group 1, we derive an explicit, linear law of motion of human capital for this group:

$$H_{t+1}^1 = [v^1(A^1/\theta^1)/(\beta - 1)] H_t^1 + [v^1(A^1/\theta^1)/(\beta - 1)] H_0^1. \quad (13)$$

Since the economy is dictated by family 1, the equation of motion (13) indicates the existence of two equilibrium regimes, depending on the magnitudes of the model's basic parameters: If the slope  $dH_{t+1}^1/dH_t^1 = v^1(A^1/\theta^1)/(\beta-1) = A^1 h_t^1$  exceeds 1,  $H_t^1$  grows exponentially without bound and the economy is in a persistent growth equilibrium regime. If the slope is below 1,  $H_t^1$  becomes constant and a stagnant-equilibrium regime ensues. The transitional development phase connecting the regimes' steady states is supported by the same parameter set that sustains the growth regime.

### 1. Stagnant Equilibrium (SE) Steady State

A stagnant equilibrium can be shown to exist when levels of the parameter set  $\{A^i/\theta^i, v^i\}$  are sufficiently low, so the optimal value of investment in human capital of family group 1 ( $h^1$ ) is below the critical level enabling a takeoff to growth, while fertility rates are relatively high when compared to their values at the growth equilibrium steady state, as shown in Section II. Except for population size ( $N^i$ ), all control and state variables, including the equilibrium income and fertility inequality measures are then constant over time.

Figure 6 illustrates the conditions that must be satisfied in this equilibrium regime. A stable stagnant equilibrium exists if the equation of motion – the evolution paths of the human capital of each family group  $H_{t+1}^i$  as a function of  $H_t^i$ , intersects the 45-degree line from above at a slope

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<sup>7</sup> For a more detailed technical analysis of the equilibrium conditions, see Ehrlich and Kim (2007).



$a_t^i(s) \equiv dH_{t+1}^i/dH_t^i < 1$ . This solution seems to reflect by and large the long historical period known as the “middle ages”. Note that the stagnant equilibrium regime is consistent with occasional fluctuations in per-capita income and distribution as a result of changes in external conditions. However, small parameter shifts are not sufficient to generate persistent growth in per-capita income or the long-term distributions of income or fertility. This may explain the absence of a continuous growth and distributional changes over the “Middle Ages.”

[Insert Figure 6]

## 2. Transitional Development Phase

An upward shock in  $\{A^i/\theta^i, v^i\}$  may trigger a takeoff into a growth equilibrium regime by raising the slopes of the evolution paths of human capital for each family above 1, which is also the condition for attaining a growth equilibrium regime. While the parameter values that may trigger a takeoff guarantee the existence of a growth equilibrium steady state, however, the effects on the pattern of the dynamic paths of income and fertility distributions will depend on the type of shock that triggers the takeoff; whether the shock is uniform and occurs synchronously across the family groups; whether it benefits one group more than the other; or whether it impacts one of the family groups with a lag. A skill-biased technological change that generates an upward increase in the technology of knowledge transfer ( $A^i$ ) and affects favorably the higher skill group can produce an inverted-U pattern of the evolution of income inequality over the transition phase, while government subsidization of education that affects favorably the lower-skill group can produce a U-shaped pattern of the evolution of income over that phase. However, all takeoff triggers affect the fertility distribution in the same direction (see below).

## 3. Growth Equilibrium (GE) Steady State

Here human capital formation grows continuously and without bound, as does per-capita income, while fertility and fertility inequality are falling. The necessary condition for attaining a growth equilibrium steady state is that the optimal investment in human capital must be sufficiently high  $h_t^i > 1/A$ . The necessary conditions for attaining a *balanced growth equilibrium* are opposite to those for obtaining a stagnant equilibrium steady state: (i). the evolution path of human capital must have a slope higher than 1, i.e.,  $a_t^i(g) \equiv dH_{t+1}^i/dH_t^i > 1$ , as is the case in Figure 6; and (ii). the fertility rate of a specific skill group ( $n^i$ ) cannot be increasing with the group size,  $N^i$ . Further

increases in the growth rate would again require an upward shock in one of the basic parameters of the model ( $A^i/\theta^i$  and  $v^i$ ). The impact on the distribution of income and fertility generally depends on the parameter effecting the change as well as the way it impacts the two family groups.

## E. Some Testable Implications

The model offers several propositions and insights concerning observed empirical evidence about the pattern of long-run income growth and distribution as well as accompanying demographic trends.

### 1. Convergence in Marginal Growth Rates of Income and Fertility

The analysis implies that both fertility rates and marginal rates of change of human capital must converge over time across families in any stable steady state. Formally, the analysis implies:

$$\begin{aligned} n_t^1 &= n_t^2 \text{ as } t \rightarrow \infty; \text{ and} \\ a_t^1 &= (dH_{t+1}^1/H_t^1) = A^1 h_t^1 = a_t^2 \equiv (dH_{t+1}^2/H_t^2) = A^2 h_t^2 (S_t^2)^\gamma. \end{aligned} \quad (14)$$

The rationale follows partly from the definition of a stable steady state in which the distribution of both income and fertility attains a stable level, but also from the role of knowledge spillover effects which function like the glue or magnet that holds equal the rates of change of both the population groups and their human capital growth, thus eliminating the prospect of a blowup in the distribution of both. Figure 7 provides a graphical proof of equation (14). If there is an exogenous shock in the economy that lowers the marginal rate of growth of human capital for the representative agent in group 2, the income inequality ratio  $E_t^2$  will rise in favor of group 2, which will then intensify the knowledge spillover effect  $S_t^2$  flowing from group 1 to 2. The process would continue until the marginal changes in the growth rates of human capital of the two groups equalize again. The same applies to the stability of the ratio of the populations of the two groups ( $N_t^1/N_t^2$ ) in the steady state, which can be maintained only if  $n_t^1 = n_t^2$ . Empirical evidence indicates that such convergence is typically observed following an external shock, such as the digital revolution in the U.S. that temporarily may raise significantly income inequality, despite the tendency of inequality to stay constant over long periods of time. The secular decline in average fertility has also tended to reduce substantially the coefficient of variation of fertility over time in the U.S.

[Insert Figure 7]

## 2. Income Inequality in Less Developed Countries

In a stable stagnant-equilibrium steady state, family-income inequality, denoted by  $E^i(s)$ , as well as the families' relative human capital attainments equal their relative inherited endowments. This result can be shown to follow from equation (14), the solution for the optimal values of investment in human capital, whereby  $h_t^{i*} = [v^i/\theta^i(\beta-1)]$ , and the need to restrict the values of the unit cost of fertility as a proportion of income to be the same for both skill groups ( $v^1 = v^2$ ). This gives the following interesting result:

$$E^2(s) = H_t^1/H_t^2 = H_0^1/H_0^2. \quad (15)$$

This result implies that status differences are the key factor determining family-income inequality in economies that are stagnant over long periods, an inference that seems compatible with historical evidence, such as the pre-industrial revolution period in Europe. Equation (15) is also dynamically stable: If a parameter shock lowers  $a^2$ , raising  $H_t^1/H_t^2$  above  $H_0^1/H_0^2$ , then  $E^2$  and  $S^2$  would also rise initially. This would raise  $h^2$  and in turn increase  $a_t^2$  and lower  $H_t^1/H_t^2$  until the initial equilibrium is restored.

## 3. The Impact of Investment Efficiencies on Income-Group Distribution

By combining equations (14) and (15) and using the optimal values of investments in human capital and fertility (derived through the first-order optimality conditions) we can show that the value of the income-group inequality measure in the stagnant equilibrium steady state is just a function of the relative ratios  $(A^1/\theta^1)/(A^2/\theta^2)$ , which we term the relative “investment efficiencies” of investing in the human capital of skill groups 1 and 2. Specifically, the group-income distribution is found to be a function of the relative investment efficiencies of the two groups:

$$S^2(s) \equiv E^2(s)P^2(s) = [(A^1/\theta^1)/(A^2/\theta^2)]^{1/\gamma} \equiv (e^1/e^2)^{1/\gamma}. \quad (16)$$

The same result is obtained for the value of the income-group inequality at the growth equilibrium steady state, which converges on the same value this measure obtained in the stagnant growth equilibrium steady state, provided the relative values of the parameters  $A^i$  and  $\theta^i$  associated with the skill groups  $i = 1, 2$  remain unchanged. This implies the strong result that if relative investment efficiencies of the two groups  $(e^1/e^2)$  remain the same at the stagnant and growth equilibria steady states, the income-group inequality measure would also become equal at these steady states.

## **F. Main Takeaways**

The distribution of personal income is highly linked to the distribution of human capital formation measures, not just at a point in time and over the lifecycle, as a vast literature in labor economics has documented, but also under dynamic, long-term conditions that allow for the process of development and sustainable growth as well as their accompanying demographic changes. Our analysis suggests that both processes, and thus the pattern of the distribution of human capital attainments and family income are driven not just by the heterogeneous conditions separating the different population groups – what we term in this analysis as skill groups – but also the effects of knowledge spillover effects generated by the disembodied component of human capital that binds them.

No general propositions can be established regarding the shape of the distribution of income inequality over the transition from a stagnant to a growth equilibrium. The shape of the dynamic path depends on the type of shock that triggers the transition and the way it impacts different family groups. While a skill-biased technological shock can generate an inverted-U shape, government educational policies favoring lower income groups can produce a U-shaped path. However, in all cases the fertility distribution is expected to become attenuated over the transition to a steady state.

Moreover, the dynamic evolution of the level and distribution of family income over the development process, and the distributional measures we use to quantify them, cannot be fully understood without recognizing their linkage to the corresponding trends in the distribution of fertility rates which are critical for understanding trends in income-group inequality or the Gini coefficient over time. The underlying trends in the level and distribution of fertility affect differently different measures of income distribution that are more sensitive to changes in the population shares of different skill groups in the economy.

## **IV. Equilibrium Migration and Human Capital and Physical Capital Formation**

### **A. Is Human Capital Relevant for Immigration?**

The relevance of human capital to immigration harkens back to our point in the introductory section that human capital cannot be separated from people. People invest in this asset in order to guarantee a larger earning capacity for both themselves and their offspring. But they have the choice to do that in the place where they were born, or seek a higher return on their investments by moving to even distant locations where they have opportunities for a better life.

So migration, whether within or across countries, is itself a kind of investment in human capital that has potential returns but also significant costs – financial and emotional – to individuals who choose to migrate.

There is one implication that immediately arises from this feature of immigration: those who freely choose to migrate are expected to obtain a positive rate of return on migrating. But this may not always be the consequence for the natives of the affected destination (receiving) or source (sending) countries. So understanding the “equilibrium” properties of immigration is an economic challenge which also has important policy implications. This is the topic of our current evolving immigration study.<sup>8</sup>

## **B. International Migration – Common Features and Some Stylized Facts**

International migration has been a persisting phenomenon since the dawn of civilization. Net migration is typically from source countries with high fertility and low human capital formation to destination countries having lower fertility and persistently higher human capital and per-capita income levels. While immigration has been growing dramatically in recent decades – by 50% worldwide from 2000 to 2017 – trends may shift, as the long-term share of immigrants in the U.S. population indicates (see Figure 8). Immigration may also come in waves – there were 30 million asylum seekers in 2016 alone.

[Insert Figure 8]

There are also significant variations in the volume of immigration within and across different regions of the world. Asian and the Pacific countries are the largest region where immigrants live, due to internal migration to destinations such as the Russian Federation and Australia. Asia as a whole, however, is a net migration region with India and the People’s Republic

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<sup>8</sup> This section builds on our working paper (Ehrlich and Pei, 2019) that is a sequel to an earlier study by Ehrlich and Kim (2015).

of China being the largest source countries (see Figure 9). One would expect a useful model of immigration to account for both the persistence of immigration and its variability across time and space. This is the focus of our analysis in this section.

[Insert Figure 9]

### **C. The Approach We Take to Explain and Assess These Features**

There is a vast literature on immigration, most of which focuses on its short-term effects in the context of a static model or the neoclassical growth model. The common feature of both approaches is the treatment of immigration as an exogenous variable. This approach is evident with some exceptions even in the recent authoritative report by the National Academy of Sciences' panel on the economic and fiscal consequences of immigration (see NAS, 2017).<sup>9</sup>

The basic innovation of the analysis in this section is treating both migration and economic growth as endogenous variables – coming from individual and family choices that are subject to external triggers – and accounting for the economic consequences of such triggers, especially in the long term. We model immigration in an open-economy setting that explores its consequences on income growth, income distribution within and across countries, and on the net benefits from immigration to the native populations in both the source (S) and destination (D) countries – a term known as “*the immigration surplus*” (IS).

The following supply and demand analysis illustrates how to figure out the IS for the destination and source countries in the short term, under static conditions.

#### **1. Why is the IS Expected to be Positive in Country D in the Short Term?**

In the short term, D's economy has a fixed quantity of technology and physical capital, so its labor demand curve is downward sloping. Any rise in labor supply due to migration lowers labor wages. Consequently labor income falls.

But total output rises: more labor yields more output, so aggregate income rises. There are therefore conflicting consequences for natives. The interesting implication of the conventional literature on immigration is that the net effect on natives as a whole is positive – this is summarized

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<sup>9</sup> For fair disclosure, Isaac Ehrlich was a member of this panel.

by the well-known result that the short-term immigration surplus is positive.

The reason is that while labor income falls as a result of diminishing returns to labor, the returns to physical capital rise. The higher return to physical capital outweighs the fall in labor income because of the larger output generated by immigrants who increase the labor supply and thus aggregate output in the economy. Immigrants are willing to accept the lower wages they induce at the destination country, since these wages remain higher than those in their home countries.

The net effect is what the literature calls the “immigration surplus” (see e.g., Borjas, 1995). This is the area **E** in Figure 10. Immigration thus creates a positive IS in the receiving country, D. By the converse logic, however, the immigration surplus must be negative in the sending country, S, in the short term, before any adjustments in the physical or human capital stocks take place.

[Insert Figure 10]

## **2. Limitations of the Static, Short-Term Immigration Surplus Measure**

The short-term IS has some limitations that need to be highlighted. First, it considers only the net income benefits to the natives, not to the immigrants. This is the case in both D and S.

Second, as Figure 10 shows, the immigration surplus in country D can be positive if, and only if, labor wages fall. Immigration yields a net gain to capital owners but a loss to workers who do not own capital. Put differently, IS ignores distributional effects.

Third, a major limitation of the immigration surplus highlighted by our analysis is that it treats immigration as an exogenous variable and ignores what has triggered it, as well as its dynamic, long-term consequences. A major result of our study is that the long-term consequences of immigration can be different from its short-term effects due to its influence on the average level of human capital and its spillover effects across the destination and source countries.

We also compute the immigration surplus after extending the concept to account for interaction effects – a two-way knowledge transfer between natives and immigrants – as a result of complementarities in knowledge formation (“diversity effects”), which enhance human capital formation. This concept is a natural extension of knowledge transfer as an enhancer of human capital formation and economic growth.

## **D. Elements of the Model**

Our story involves two countries – destination (D) and source (S) – which are both in a growth equilibrium regime. As a point of reference we allow for free international mobility of labor. We allow for two periods of life – childhood and parenthood. Each country ( $i = d, s$ ) also has two segmented good-producing sectors ( $j = 1, 2$ ) – high-tech and low-tech – which exclusively employ high-skilled and low-skilled workers ( $j = 1, 2$ ), respectively. In country D, these workers include immigrants as well. Immigrants' children, however, are treated as natives.

D is more developed technologically than S: both the technologies of knowledge transfer ( $A$ ) and the technologies of goods production ( $\Gamma$ ) are higher in D relative to S ( $A^{dj} > A^{sj}$  and  $\Gamma^{dj} > \Gamma^{sj}$ ,  $j = 1, 2$ ), while, by definition, the corresponding technologies are higher for the high-skilled relative to lower-skilled workers and the high-tech sector, relative to the low-tech sector, ( $A^{i1} > A^{i2}$  and  $\Gamma^{i1} > \Gamma^{i2}$ ,  $i = d, s$ ) respectively. At the same time we need to assume that the unit costs of fertility as a fraction of potential income must be higher in D relative to S, but are the same across the two skill groups within each country ( $v^d > v^s$  for all  $j$ ). These are necessary modeling conditions that must be imposed to obtain interior, balanced-growth, equilibrium solutions that allow for the possibility of continuous migration across countries while also preserving the populations of the different skill groups within countries.

The global economy is thus comprised of 6 distinct population groups and representative decision-makers: high- and low-skilled natives in two countries, including high- and low-skilled immigrants. Parents are altruistic. They want better life for their children. So they make consumption, bequest, fertility, and human-capital investment decisions, as well as migration decisions. Children thus benefit from both parental human capital investment and any bequests they receive in adulthood. Optimal immigration is determined at the point where the net utility benefits to those who choose to migrate from S to D are equally productive on the margin as those who choose to stay in S – an arbitrage condition.

### **1. Human Capital Spillover Effects and Equilibrium Migration**

To derive a balanced growth equilibrium in D and S, we must allow for spillover effects of human capital, not just between parents and offspring or across skill groups within each country (including the immigrant groups in D), but also across countries. International spillover effects may include financial remittances. But we focus especially on the role of knowledge transfers via



spillover effects. In our benchmark model they are one-sided and hierarchical: they flow from the high-skill sector to the low-skill sector within countries, and from each sector in D to the corresponding one in S, due to the superior technologies of producing both human capital and industrial products in D relative to S. The magnitudes of these spillover effects are proportional to the weighted average of human capital in D relative to S, where the weights are the relative population sizes of the relevant skill groups. The larger the size of each skill group – including immigrants – in D, the bigger the spillover effects on the corresponding groups in S.

The one-sided spillovers are also gravitational: they pull all skill groups within and across countries together into equilibrium growth paths that grow at the same rate over time. This assures the existence of balanced growth global equilibrium that avoids “corner solutions”.

## 2. The Formal Setup in the Benchmark Model

Formally, our specification of the human capital formation process and associated spillover effects are given by the following 6 production functions of 6 skill groups of workers in the global economy: 2 skill groups of natives in 2 countries ( $i = d, s; j = 1, 2$ ); and 2 skill groups of immigrants ( $i = m; j = 1, 2$ ). The corresponding production functions are:

$$H_{t+1}^{d1} = A^{d1} h_t^{d1} H_t^{d1} \quad \text{for skilled natives in D,} \quad (17a)$$

$$H_{t+1}^{d2} = A^{d2} h_t^{d2} H_t^{d2} \left( \Delta_t^{dd2} \right)^{\gamma^1} \quad \text{for unskilled natives in D,} \quad (17b)$$

$$H_{t+1}^{m1} = A^{d1} h_t^{m1} H_t^{s1} \quad \text{for skilled immigrants in D,} \quad (17c)$$

$$H_{t+1}^{m2} = A^{d2} h_t^{m2} H_t^{s2} \left( \Delta_t^{dd2} \right)^{\gamma^1} \quad \text{for unskilled immigrants in D,} \quad (17d)$$

$$H_{t+1}^{s1} = A^{s1} h_t^{s1} H_t^{s1} \left( \Delta_t^{ds1} \right)^{\gamma^2} \quad \text{for skilled natives in S,} \quad (17e)$$

$$H_{t+1}^{s2} = A^{s2} h_t^{s2} H_t^{s2} \left( \Delta_t^{ds2} \right)^{\gamma^2} \left( \Delta_t^{ss2} \right)^{\gamma^1} \quad \text{for unskilled natives in S,} \quad (17f)$$

where  $H_t^{ij}$  is the attained level of human capital of the 6 skill groups;  $h_t^{ij}$  is the share of earning capacity that parents in these groups invest in each child, and  $A^{ij}$  are the endowed knowledge transfer technologies which augment the productivity of the corresponding investments in human capital  $h_t^{ij}$ . As indicated earlier, the knowledge-production-and-transfer technology is higher in D

relative to S,  $A^{dj} > A^{sj}$ , while it is also higher for the high-skilled relative to the lower-skilled workers within each country,  $A^{i1} > A^{i2}$ .

The spillover effects in equations (17b) and (17d)-(17f),  $\Delta^{ij}$ , are proportional to the relative human capital attainments of the interacting groups, weighted by their corresponding population shares – the equivalent of the knowledge spillover effect terms in equation (8).<sup>10</sup> The spillover effects flow from the higher to the lower skill group within D and S, and from skill  $j$  in D to the respective skill  $j$  in S. These effects are subject to diminishing returns:  $\gamma^j < 1$ .

### 3. Optimization and Arbitrage Condition

Each representative parent in country  $i = \{d, s\}$  and skill group  $j = \{1, 2\}$  is assumed to maximize the utility of own consumption and the psychic returns from altruistic sentiments. Note that the altruism function in this model is expanded to account for the utility to parents from the bequest of physical capital they leave for their children, which becomes the physical capital endowment inherited by the offspring's generation. Formally, the maximization problem for each of the heads of the 6 population groups comprising the world's population is maximizing

$$U^{ij} = [1/(1 - \sigma)](C_t^{ij})^{1-\sigma} + \delta[1/(1 - \sigma)](W_{t+1}^{ij})^{1-\sigma}, \quad (18)$$

where the altruism benefits are given by

$$W_{t+1}^{ij} = B (n_t^{ij})^\beta (w_{t+1}^{ij} H_{t+1}^{ij})^\eta (r_{t+1}^{ij} K_{t+1}^{ij})^{1-\eta}, \quad (19)$$

subject to the budget constraint on native parents' lifetime consumption ( $C_t^{ij}$ ) and bequest ( $K_{t+1}^{ij}$ ),

$$C_t^{ij} + n_t^{ij} K_{t+1}^{ij} = r_t^{ij} K_t^{ij} + (1 - v^i n_t^{ij} - \theta^{ij} h_t^{ij} n_t^{ij}) w_t^{ij} H_t^{ij}, \quad (20)$$

and the production functions of human capital (17) and high-tech and low-tech goods:

$$Q_t^{ij} = \Gamma^{ij} (K_t^{ij})^\alpha (H_t^{ij} L_t^{ij})^{1-\alpha}, \quad (21)$$

where  $n_t^{ij}$  and  $h_t^{ij}$  are the number of children and investment of human capital per child, and  $v^i$  and  $\theta^{ij}$  are the unit costs of raising and financing a child's educational investments, respectively. In the goods production function (21),  $\Gamma^{ij}$  denotes the productivity parameter, or production technology augmenting goods production, and  $H_t^{ij} L_t^{ij}$  stands for the effective labor

<sup>10</sup> More Specifically, the relevant spillover effects are:  $\Delta_t^{dd2} = (N_t^{d1} H_t^{d1} + M_t^{s1} H_t^{s1}) / (N_t^{d2} H_t^{d2} + M_t^{s2} H_t^{s2})$ ;  $\Delta_t^{ss2} = (N_t^{s1} H_t^{s1} - M_t^{s1} H_t^{s1}) / (N_t^{s2} H_t^{s2} - M_t^{s2} H_t^{s2})$ ;  $\Delta_t^{ds1} = (N_t^{d1} H_t^{d1} + M_t^{s1} H_t^{s1}) / (N_t^{s1} H_t^{s1} - M_t^{s1} H_t^{s1})$ ; and  $\Delta_t^{ds2} = (N_t^{d2} H_t^{d2} + M_t^{s2} H_t^{s2}) / (N_t^{s2} H_t^{s2} - M_t^{s2} H_t^{s2})$ .

input in production, which, in country D includes immigrants as well. While we assume that  $\Gamma^{ij}$  is higher in D relative to S (see Section IV.D), the ratio  $\Gamma^{i1}/\Gamma^{i2}$  must be equal across the high-tech and low-tech sectors in each country.

For migrants, the optimization problem is the same, except that the budget constraint is given by

$$C_t^{mj} + n_t^{mj} K_{t+1}^{mj} = (1 - \tau^{kj}) r_t^{dj} K_t^{sj} + (1 - v^s n_t^{mj} - \theta^{sj} h_t^{mj} n_t^{mj} - \tau^{hj}) w_t^{dj} H_t^{sj}, \quad (22)$$

where  $\tau^{hj}$  and  $\tau^{kj}$  stand for migration costs in terms of foregone wage and nonwage income (opportunity and transaction costs on assets), respectively. The arbitrage condition for the representative migrant underlying the decision to migrate from S to D is given by

$$(C_t^{sj})^{1-\sigma} + \delta(W_{t+1}^{sj})^{1-\sigma} = (C_t^{mj})^{1-\sigma} + \delta(W_{t+1}^{mj})^{1-\sigma}. \quad (23)$$

As we showed in Section II, the necessary condition for attaining a balanced growth equilibrium is that the rate of investment in human capital as a fraction of production capacity of the leading skill group in country D must exceed a critical level, given by<sup>11</sup>

$$dH_{t+1}^{ij}/dH_t^{ij} = A^{d1}(h_t^{d1})^* = (v^d \eta) (A^{d1}/\theta^{d1})/(\beta - 1) = (1 + g^*) > 1. \quad (24)$$

This model is too complex to be solved analytically via any closed-form solutions. We therefore resort to simulation analysis to solve for the key control and state variables of the model. What facilitates the existence of general equilibrium interior solutions, which include an equilibrium flow and stock of migrants are: (i) the knowledge spillover effects running from the top skill group in the high-tech sector of country D (which includes high-skilled migrants as well) to both its counterpart in country S and the lower skill group in the low-tech sector in country D (which includes low-skilled migrants as well); and (ii) the similar knowledge spillover effects running from the top skill group in the high-tech sector in country S to the lower skill group in the low-tech sector in the same country. The global equilibrium, stabilized by hierarchical knowledge spillover effects, is illustrated in Figure 11.

[Insert Figure 11]

#### 4. Extended Model: Recognizing Spillover Effects from Diversity

Our baseline model is based on the premise that knowledge spillover effects are largely

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<sup>11</sup> Additional constraints must be imposed on the ratios of human capital investment efficiencies, and goods production efficiencies to be equal across all skill groups within and across countries, i.e.,  $(A^1/\theta^1)/(A^2/\theta^2)$ , and  $\Gamma^{i1}/\Gamma^{i2}$  must be equal across countries ( $i = d, s$ ) in order for the required balanced growth equilibrium to exist.

hierarchical, running from the population group with the highest level of acquired knowledge to groups with lesser attained knowledge, which can therefore benefit from knowledge spillover effects. However, knowledge-transfers can also be two-sided, or interactive, as well as hierarchical. The interaction between immigrants and natives can produce more human capital because of complementarities in knowledge production, or two-way spillover effects, between the diverse interacting groups, essentially because diversity in the process of knowledge formation is itself a source of efficiency in knowledge creation.

A formal way to express the benefits from diversity in knowledge formation is by modifying the knowledge transfer technological parameter  $A^{ij}$  in equation (1) to account for the two-way interaction variable  $d^j$ , as follows:

$$\bar{A}^{dj}(d^j) = A^{dj}(1 + d^j)^\rho, \quad (25)$$

where  $d^j = M^{sj} / (N^{dj} + M^{sj})$  represents the share of the immigrants' stock in country D's population.

While diverse workers may raise communication costs due to differences in language and culture, the interaction between natives and immigrants of the same skill level raises the productivity of knowledge-generation, especially across workers of the same skill level who acquired their knowledge and skill in independent environments (the classical example being the Manhattan project). We consider these diversity effects in our extended model, when estimating the relevant immigration surplus implied by that model.<sup>12</sup>

## E. Numerical Solutions of the Benchmark Model and the Impact of Parameter Shifts

Table 1 presents numerical solutions of the global equilibrium system illustrated in Figure 11, generated by calibrated simulations using data associated with the average groups of source and destination countries in Asia and the Pacific from 1962 to 2017. The group of destination countries and economies include Australia, Japan, Republic of Korea, Singapore, and Hong Kong, China; while the group of source countries include the countries of origins of immigrants in these destination countries and economies.

[Insert Table 1]

---

<sup>12</sup> Some evidence on favorable productivity effects of diversity is provided in Alesina, Harnoss and Rapoport (2016).

The top row records the steady-state solutions for the control and state variables of the benchmark model – fertility, investment in human capital, the growth rate of human and physical capital, the country- and skill-specific knowledge spillover effects, and the share of high-skilled migrants in the total stock of migrants residing in the destination countries. The latter variable exerts a critical influence on the long-term net benefits of immigration for the destination and source countries, respectively. The lower rows of Table 1 indicate the way the equilibrium values of the same control and state variables change as a consequence of exogenous shocks in some of the basic parameters of the model. These shocks can also be thought of as representing two main immigration-inducing factors:

i. *Pull Factors*. For example, a skill-biased technological shock (SBTS) – the digital/internet revolution starting in the late 1960s – which we interpret as shifting upward the technology of knowledge generation and the technological prowess of the high-skilled workers in both D and S –  $A^{d1}$  and  $A^{s1}$ . This shock is shown to increase the rate of growth of human and physical capital, and thus income per-capita as well, in both D and S, as illustrated in the second row of Table 1.

Another pull factor illustrated in the third row of Table 1 is a sharp drop in the fertility level in the destination country due to exogenous factors, such as a structural change in the economy that induces a larger participation of women in the labor force, and thus raises the opportunity costs of bearing and raising children,  $v^d$ . This latter effect also generates an upward change in the growth rate of human and physical capital, largely because it induces a decline in fertility, but a rise in parental investments in human capital per child (a quantity-quality substitution effect) and thus in per-capita income in both D and S.

ii. *Push Factors*. The one we illustrate in the fourth row of Table 1 is an adverse productivity shock due to war, famine or political instability in the source country, captured by a fall in the technological parameter affecting goods production in both sectors of the source country – a downward shift in the parameters  $\Gamma^{sj}$ . This change initially raises aggregate income in D and lowers it in S, but causes no growth effects in either D or S.

## **F. Long-Term Effects of Immigration Triggers on the IS under the Benchmark Model**

In the static context, the effects of any immigration triggers on the short-term immigration

surplus are always positive in D and negative in S, as predicted by the conventional, or neoclassical models of immigration. In the context of our model, however, where both growth and immigration as well as their basic determinants are endogenous variables, the static analysis cannot predict the long-term evolution of the immigration surplus following a change in immigration generated by a specific immigration trigger. To do that, we need to assess the level and direction of changes in the immigration surplus by isolating from the total effect of the trigger on the economy, as summarized in Table 1, the “pure” immigration effects induced by the rise in migration flows of high-skilled and low-skilled workers from S to D. To do this, we assess the percentage difference between the unrestricted total effects of any immigration trigger and the latter’s hypothetical effects if immigration flows were restricted to remain unchanged at their initial equilibrium levels. Table 2 summarizes the dynamic effects of these “pure” immigration effects in the context of our benchmark model.

[Insert Table 2]

Generally, the long-term effects of immigration changes on the IS depend on type of the external shock – the pull or push factors that have triggered them. Under a skilled-biased technological shock, which is a pull factor, the IS rises in D and falls in S. This is essentially because SBTS induces a rise in the skill composition of migrants – the share of high-skilled migrants in the total flow and stock of skilled workers in the population. Some evidence supporting the validity of this result is illustrated in Figure 12 showing that in four of the largest destination countries – the U.K., France, Australia, and Canada, the weighted averages of the skill composition of the migrant population have even exceeded those of the total domestic populations in the corresponding countries over the period 1975-2010 – a period in which the digital revolution may have triggered a SBTS shock in the destination countries. More importantly, this induced-immigration effect raises the average human and physical capital stocks in the economy, and thus the level of the per-capita income in D, which is the key determinant of the level and direction of the change in the immigration surplus. The rise in the skill composition of emigration from S exerts the opposite effects in S, which experiences a “brain drain”. Consequently, the immigration surplus in S falls, while that in D rises.

[Insert Figure 12]

Under a downward fertility shock in D or an adverse productivity shock in S, the immigration surplus falls in D and rises in S. This is because both shocks raise the volume of

immigration flows from S to D, without any increase in their skill composition. Since immigrants come from source countries where the average level of human and physical capital is lower by our model, the corresponding immigration waves into D thus lower the average per-capita human and physical capital levels in D, causing a decline in the immigration surplus in D. But the higher population of skilled and unskilled workers in D raise the intensity of the knowledge spillover effects running from D to S, which raises the average human capital in S. The immigration surplus in S thus increases.

In general, under the benchmark model, immigration triggers generally produce asymmetric changes in the immigration surplus in the destination and source countries D and S. The underlying reason is that individual migrants do not internalize the externalities generated by the spillover effects of their decision to migrate on the native populations in both their home and destination countries.

### **G. Long-Term Effects of Immigration Triggers on the IS under the Extended Model**

Allowing for spillover effects from diversity, which generate complementarities in knowledge production between migrants and natives, alters to some extent the level and direction of the induced immigration effects of the pull and push factors considered in the previous section.

First, any external shock that increases immigration from S to D is expected to raise the growth rate of human capital formation in D, and thus in per-capita income in D. The knowledge spillover effects running from the increased levels of the skill groups in D assure that the growth rate of per-capita income will rise in S as well, as the growth rates of all skill groups ultimately converge on that of the top skill group in D. However, the net effects on the immigration surplus also depend on the impact of the trigger on the skill composition of workers in the two countries, as indicated by Table 3.

[Insert Table 3]

Under a skill-biased technological shock, the *asymmetry* in the consequences of the SBTS trigger between D and S remains: while the gain in the immigration surplus becomes larger in D – it rises by 1.28% in D after 10 periods in the extended model relative to 1.14% in the benchmark model – there is still a loss in the immigration surplus in S due to reduction in the population share of high-skilled natives and thus in the average corresponding levels of human and physical levels

and per-capita income. Indeed, the loss level remains similar to that under the benchmark model: -14.12% after 10 periods, relative to -14.11% in the benchmark model.

Under a downward fertility shock in D, the immigration surplus now turns positive rather than negative as it was in the benchmark model, while it continues to be positive in country S. This is a *win-win* outcome due to the assumed interactive diversity effects of immigration in the receiving country. This may provide some explanation to the receptiveness of a number of European countries to immigration surges in recent decades.

Under an adverse productivity shock in S, the immigration surplus is found to turn positive in D for 3 consecutive periods, but it then slides down in a negative direction. The initial gain in the immigration surplus is due to the interactive diversity effects, while the later loss is due to the lower average human capital of migrants relative to those of the natives in D, which outweighs the diversity benefits. The immigration surplus continues to be positive in the sending country, S.

## **H. Policy Implications**

### **1. Asymmetries in the Net Gain from Immigration across Destination and Source Countries**

Our simulations, especially under the benchmark model, reveal that changes in the IS in D and S tend to be asymmetrical in response to both pull and push factors not just in the short run, but in the long run as well. This calls for an explanation, which we take up in the next subsection.

For example, a SBTS raises IS in D and lowers it in S, while the adverse fertility shock in D or productivity shock in S lower the IS in D and raise it in S. At the same time, we find that in most cases, immigration lowers income inequality across D and S because of the spillover effects running from skilled groups in D to their counterparts in S, which lower the percentage income gap between the two.

### **2. Externalities and the Political Stability of Immigration**

The essential reason for the asymmetry in the immigration surplus generated by both pull and push forces may be related to the fact that free migration may inevitably impose *negative externalities* on natives, since individual decisions to migrate do not consider any adverse consequences to natives in either D or S. So while there exists a balanced growth equilibrium under



unrestricted immigration, it may be *unstable politically*. Note that in this analysis we consider only the economic consequences of migration. We ignore the fiscal burdens of immigration in D, which may worsen the IS for natives in D even in the short term.

This explains why most independent countries resort to regulatory intervention in the form of restrictive immigration policies, or to bargaining solutions; for example, the U.S. aid to Central America when immigration waves were triggered by adverse productivity shocks in these sending countries.

A superior solution, however, would be more investments in human capital in the sending countries – especially in higher education, which puts a check on the incentive to emigrate while allowing higher education to produce higher growth in sending countries. But this solution works if the economic policies promote competitive labor markets to provide an adequate rate of return to investment in higher education. This may have been one of the reasons the Morrill Act had been successful in raising the rate of productivity growth in the U.S. due to the dominant share of the private sector in the U.S. in the 19<sup>th</sup> century.

There is, of course, an altruistic solution as well: a special allowance, for example, for asylum seekers and refugees.

## **V. Concluding Remarks – The Role of Knowledge Spillover Effects**

We began this paper by highlighting the role of disembodied human capital and its spillover effects in enabling the attainment of a balanced growth equilibrium (BGE). Each of the studies we covered in this paper relies at least on one of the following channels that play a critical role in enabling a BGE:

First, knowledge spillover effects across generations in models of homogeneous agents or a representative agent.

Second, knowledge spillover effects across different skill groups in models of heterogeneous agents in a closed economy, which enable a BGE involving both income growth and income distribution within an economy.

Third, knowledge spillover effects across heterogeneous skill groups within and across countries. These effects could be hierarchical, flowing from the group with greater knowledge to the one with lesser knowledge, or two-sided because of complementary “diversity effects”.

Equilibrium immigration flows under balanced growth regimes are enabled due to the spillover effects operating through all of the abovementioned channels.

Spillover effects by definition impart external effects on others, which in many cases may also involve externalities, since not all the benefits from spillover effects can be internalized. The extent of externality effects may be minor when spillover effects take place between parents and offspring, but it may be more serious in the case of immigration for two reasons:

First, cross-country externalities, like intellectual property, are more difficult to internalize. Their presence generally leads to underinvestment in human capital and explains why destination countries may be especially concerned about protecting technological property rights as part of trade agreements. A case in point may be the current trade dispute between the U.S. and the People's Republic of China.

Second, the immigration decision by itself has an inherent externality problem because individual decisions to migrate are motivated by the net benefit to the individual but they do not account for their long-term consequences for natives in both destination and source countries. As our paper points out, they generally result in opposite net benefits from immigration across countries in the long term. The asymmetry leads to politically unstable equilibria, and explains why in most economies, immigration is subject to some restrictive policies, especially in the case of unskilled migration.

Recognizing these externalities opens the door for policy interventions aiming at maximizing the benefits from human capital as engine of national and global economic development and balanced growth.

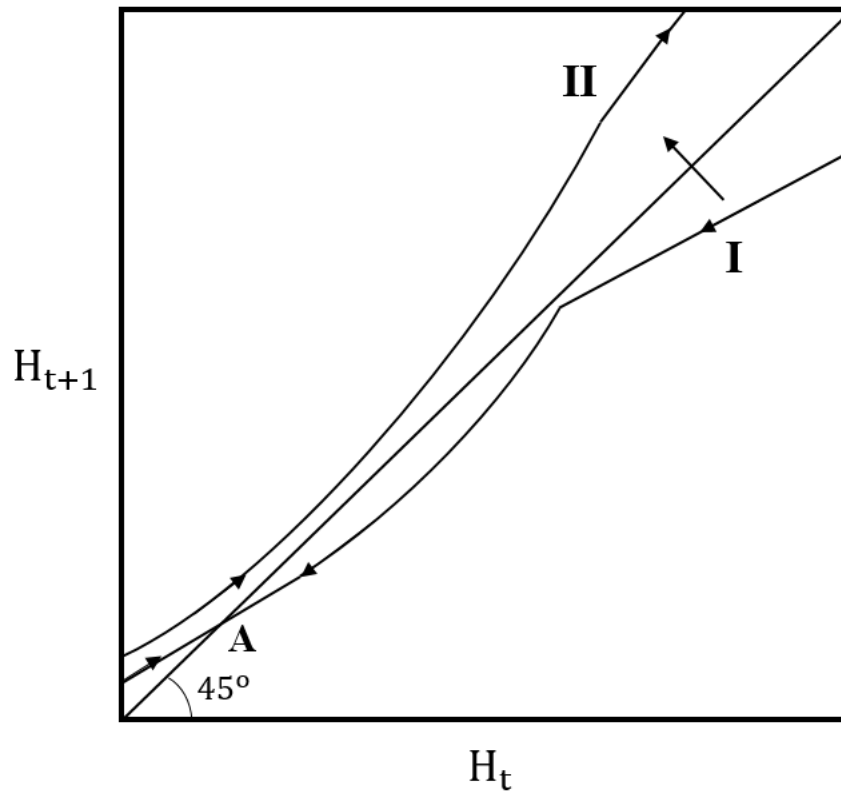
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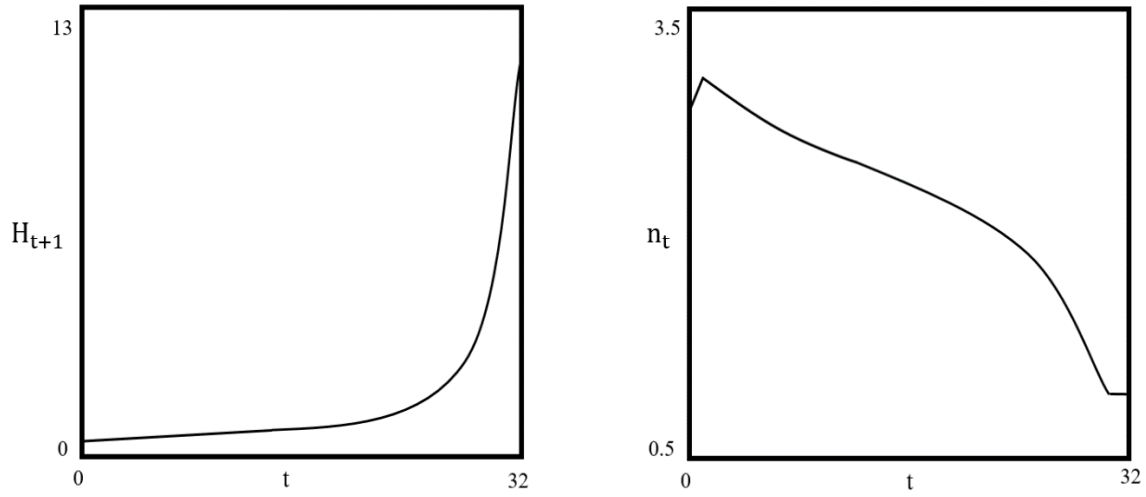
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**Figure 1. Takeoff to Growth**



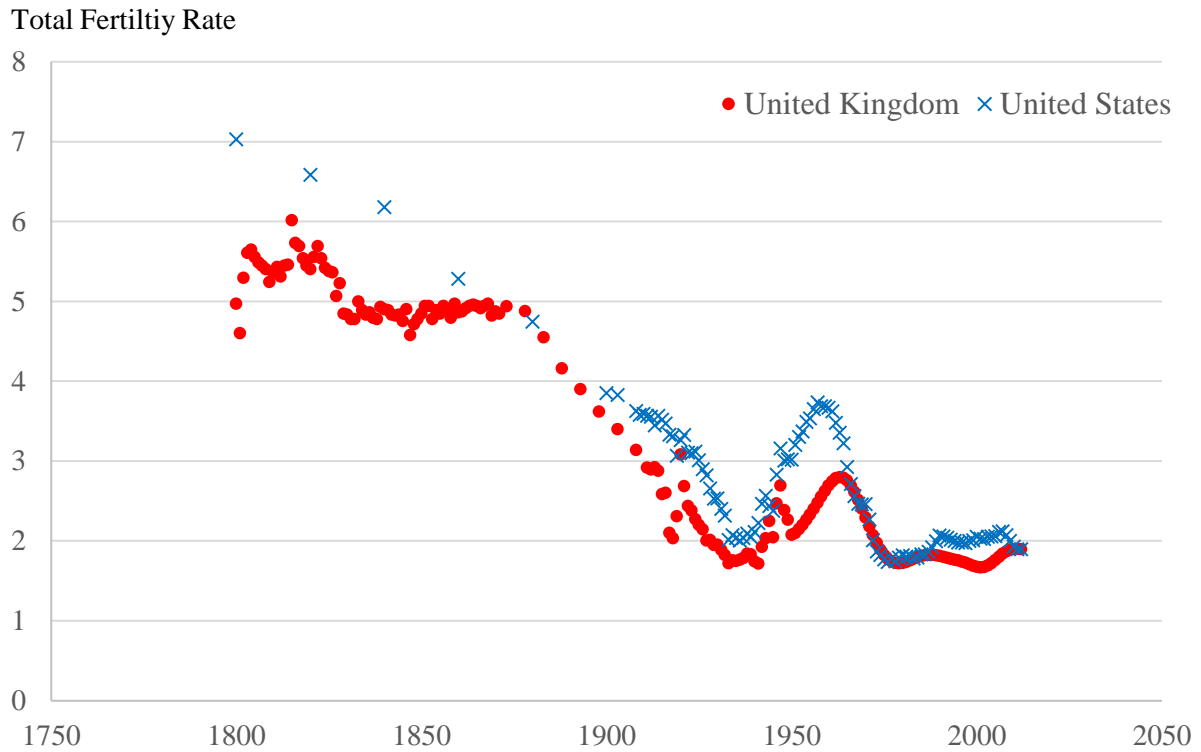
Notes: The figure is reproduced from Ehrlich and Lui (1991). The figure shows possible dynamics after an exogenous increase in longevity: A sufficient increase in longevity can shift the Human Capital phase line above the 45-degree line. For parameter values see footnote 4.

**Figure 2. Demographic Transition**



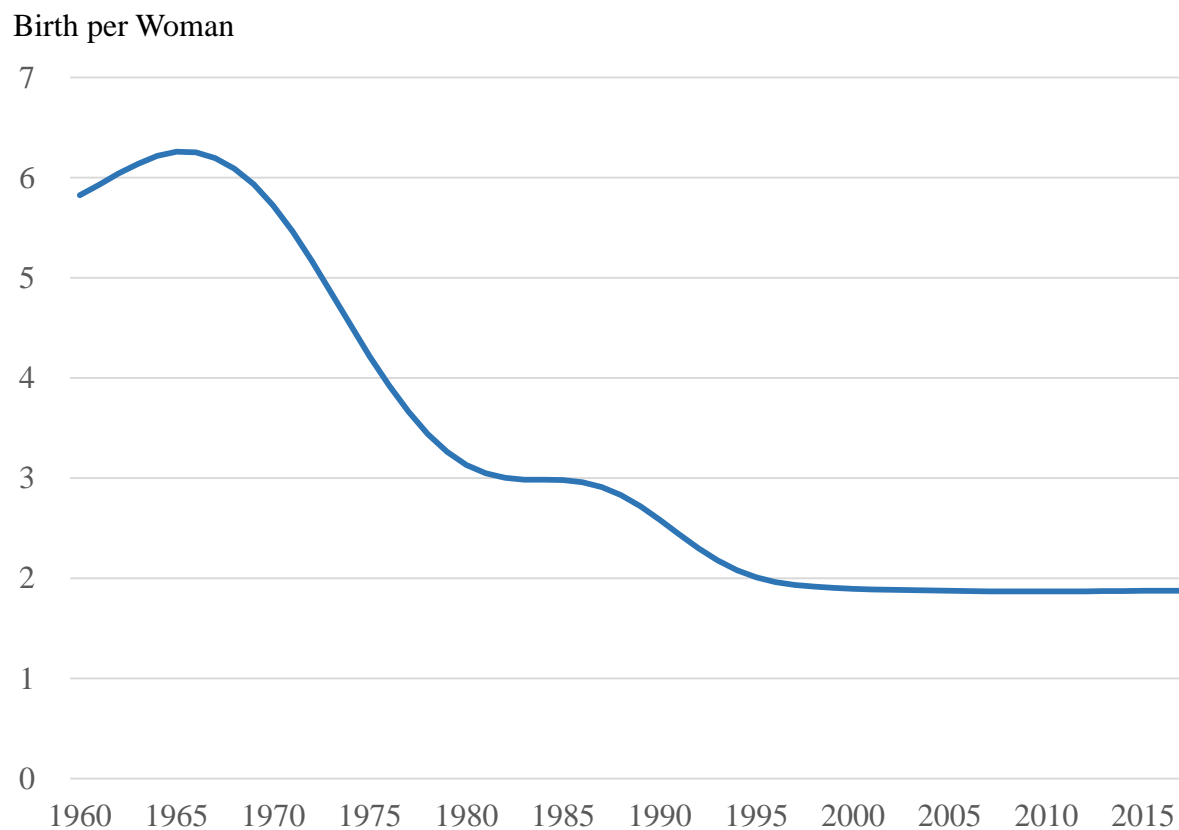
Notes: The figures are reproduced from Ehrlich and Lui (1991). The figures show the simulated paths of human capital and fertility in response to an upward shock in the life expectancy of children that lifts Human Capital formation from a stagnant to an endogenous growth regime, shown in Figure 1. For parameter values see footnote 4.

**Figure 3. Total Fertility Rates in the United Kingdom and the United States over Time**



Source: Princeton European Fertility Project, <http://www.gapminder.com>.

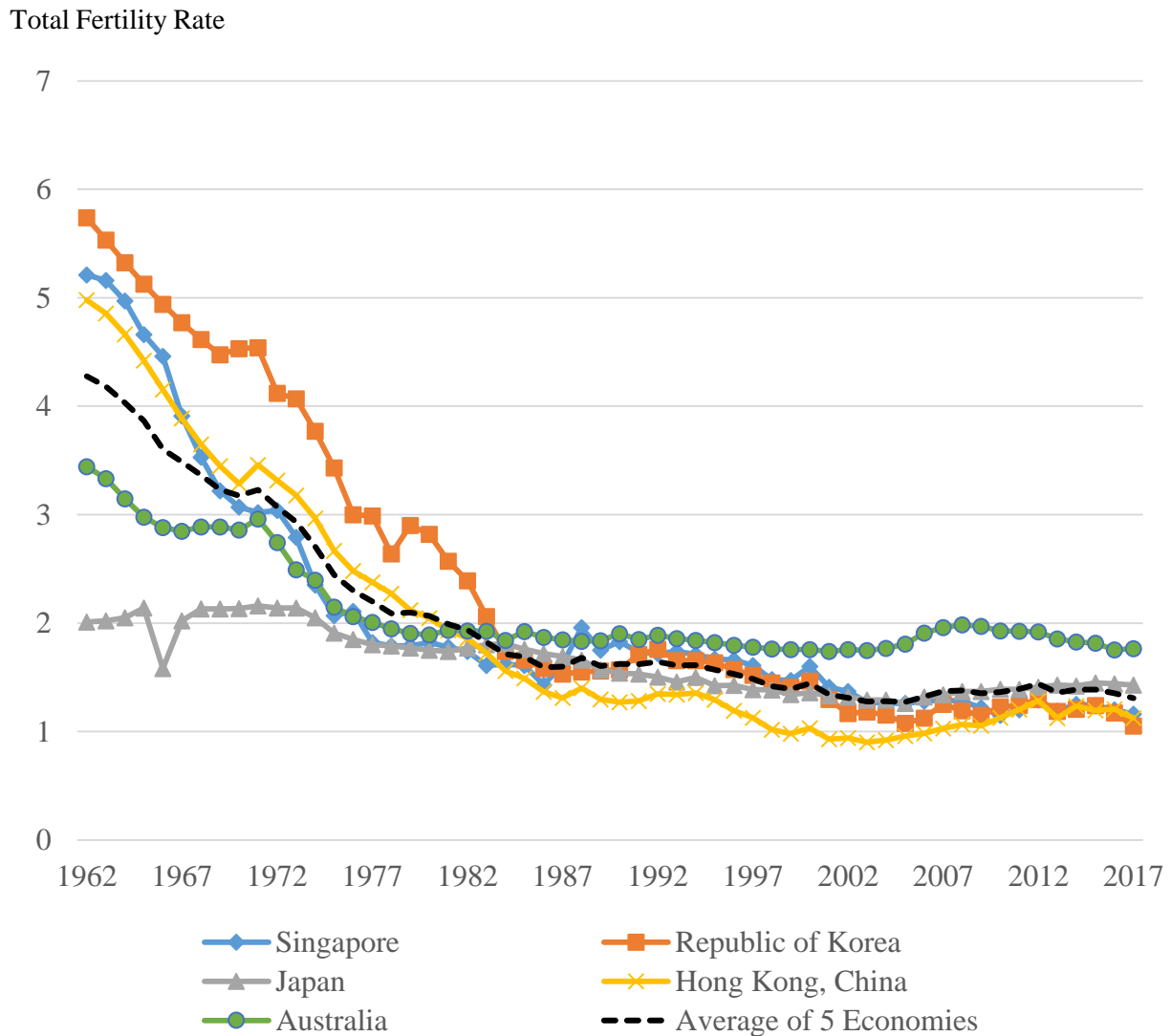
**Figure 4. Total Fertility Rate of Developing Countries in East Asia and Pacific, 1960-2017**



Source: <https://fred.stlouisfed.org/series/SPDYNTFRTINEAP>.

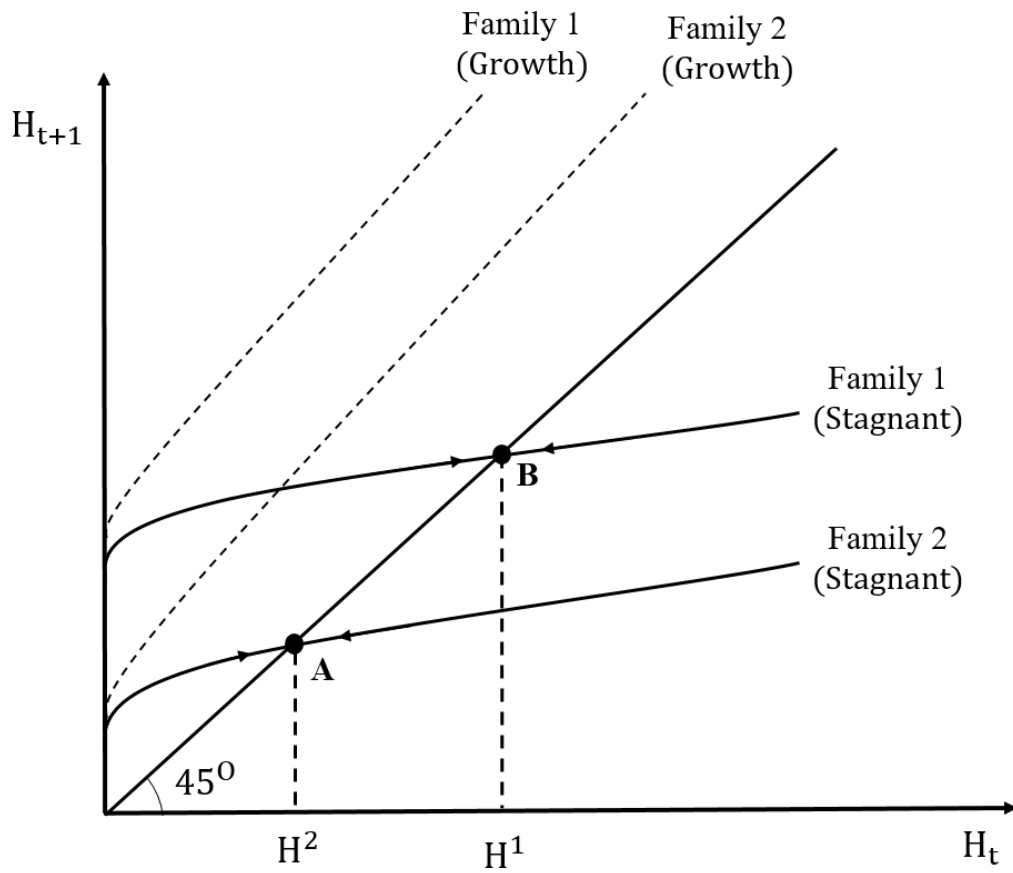


**Figure 5. Total Fertility Rates of 5 Fast Developing East Asia-Pacific Economies, 1962-2017**

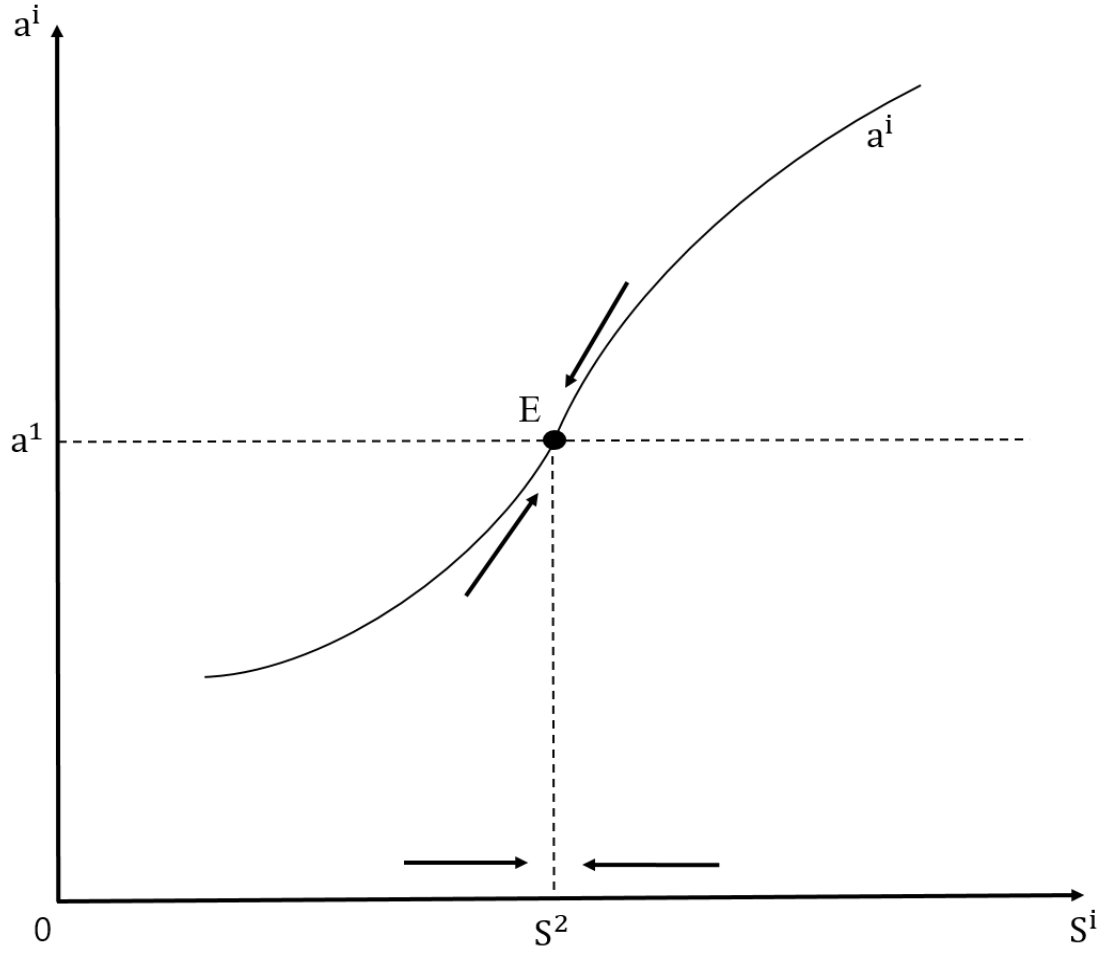


Source: World Development Indicators, <https://data.worldbank.org/indicator/sp.dyn.tfrt.in>.

**Figure 6. Stagnant and Growth Equilibrium**

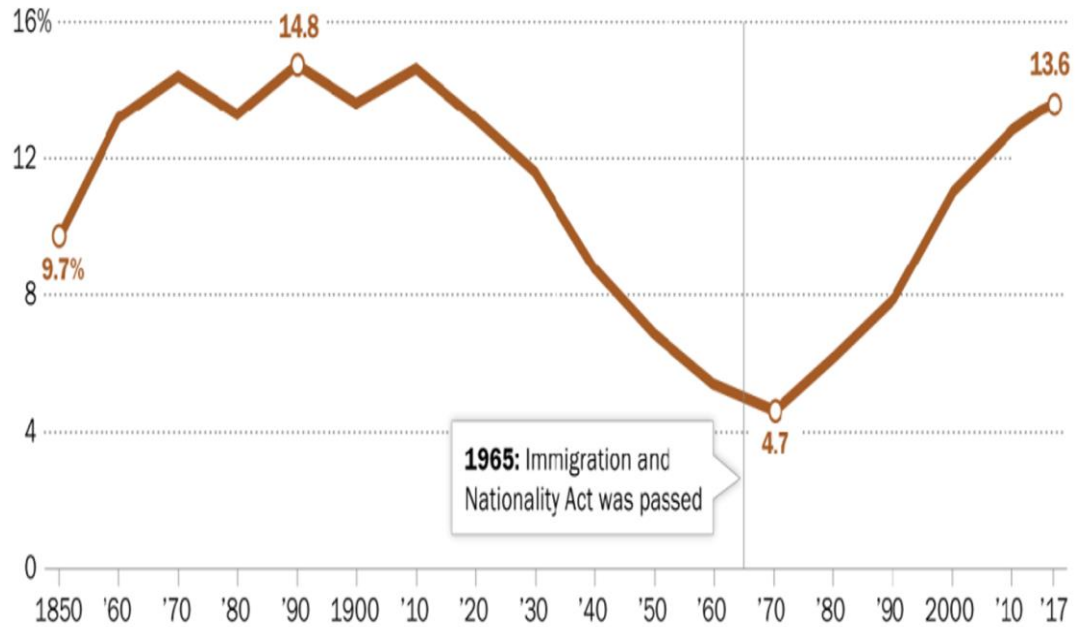


**Figure 7. Equilibrium Solutions for Marginal Growth Rates ( $a^i$ ) and Spillover Effects ( $S^2$ )**



Notes:  $a_t^1 \equiv (dH_{t+1}^1/dH_t^1) = A^1 h_t^1$ ;  $a_t^2 \equiv (dH_{t+1}^2/dH_t^2) = A^2 h_t^2 (S_t^2)^\gamma$ ;  $S_t^2 \equiv [(H_0^1 + H_t^1)/(H_0^2 + H_t^2)][(N_t^1/N_t^2)]$ .

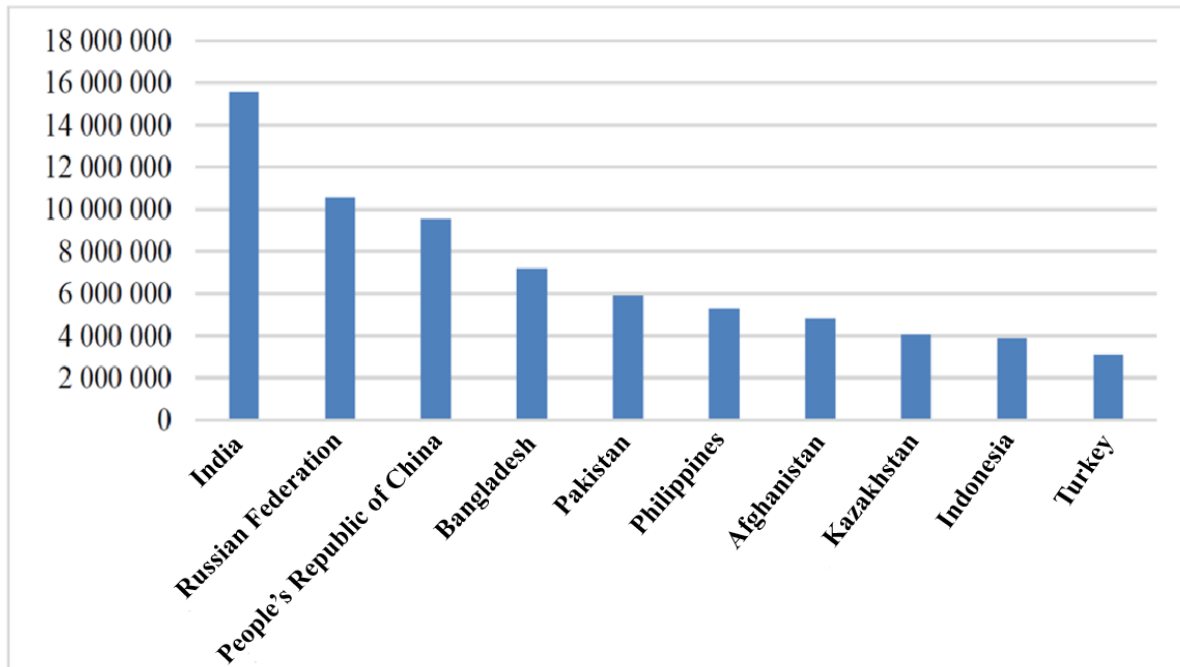
**Figure 8. Immigrant Share of the United States Population, 1850-2000**  
(% of the United States population that is foreign born)



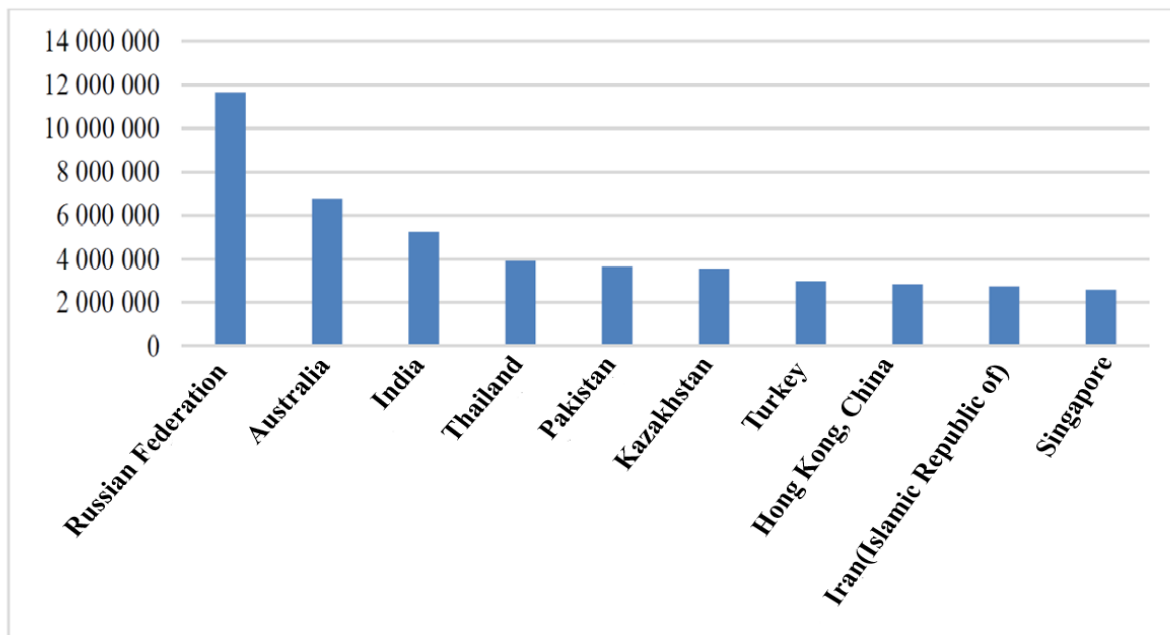
*Source:* The United States Census Bureau, “Historical Census Statistics on the Foreign-Born Population of the United States: 1850-2000” and Pew Research Center tabulation of 2010 and 2016 American Community Survey (IPUMS).

**Figure 9. Top 10 Countries of Origin and Destination in Asia and the Pacific**

■ Top 10 Countries of Origin in Asia and the Pacific, 2015 (Number of Migrants)

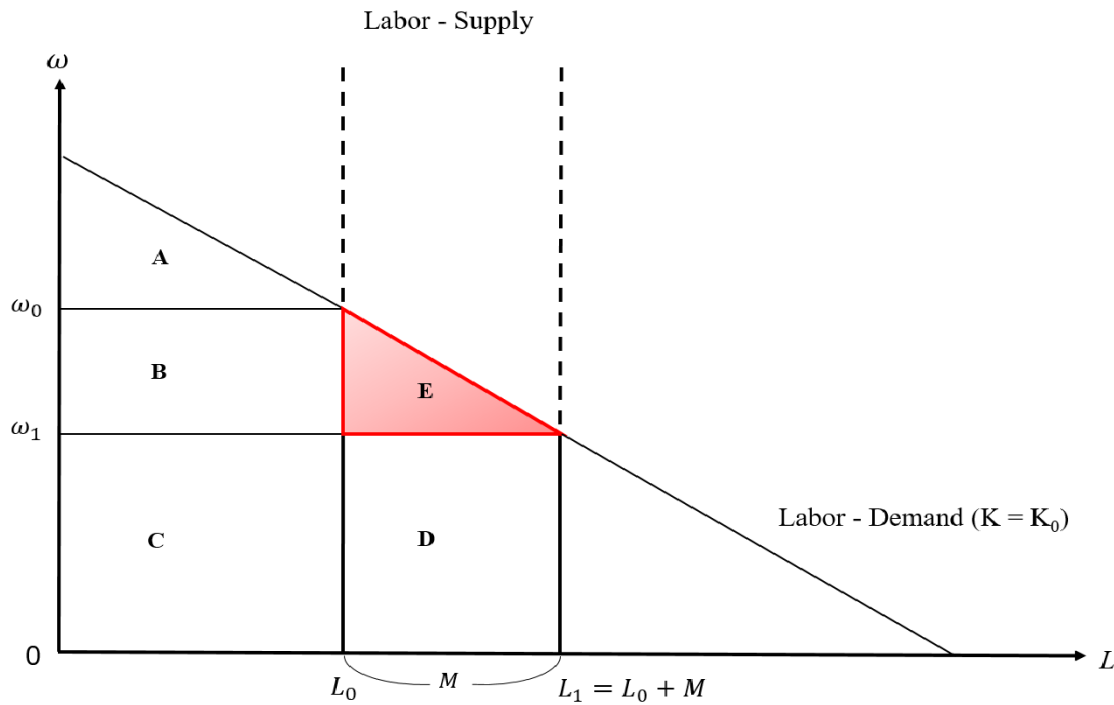


■ Top 10 Countries of Destination in Asia and the Pacific, 2015 (Number of Migrants)



Source: United Nations, "Trends and drivers migration in Asia".

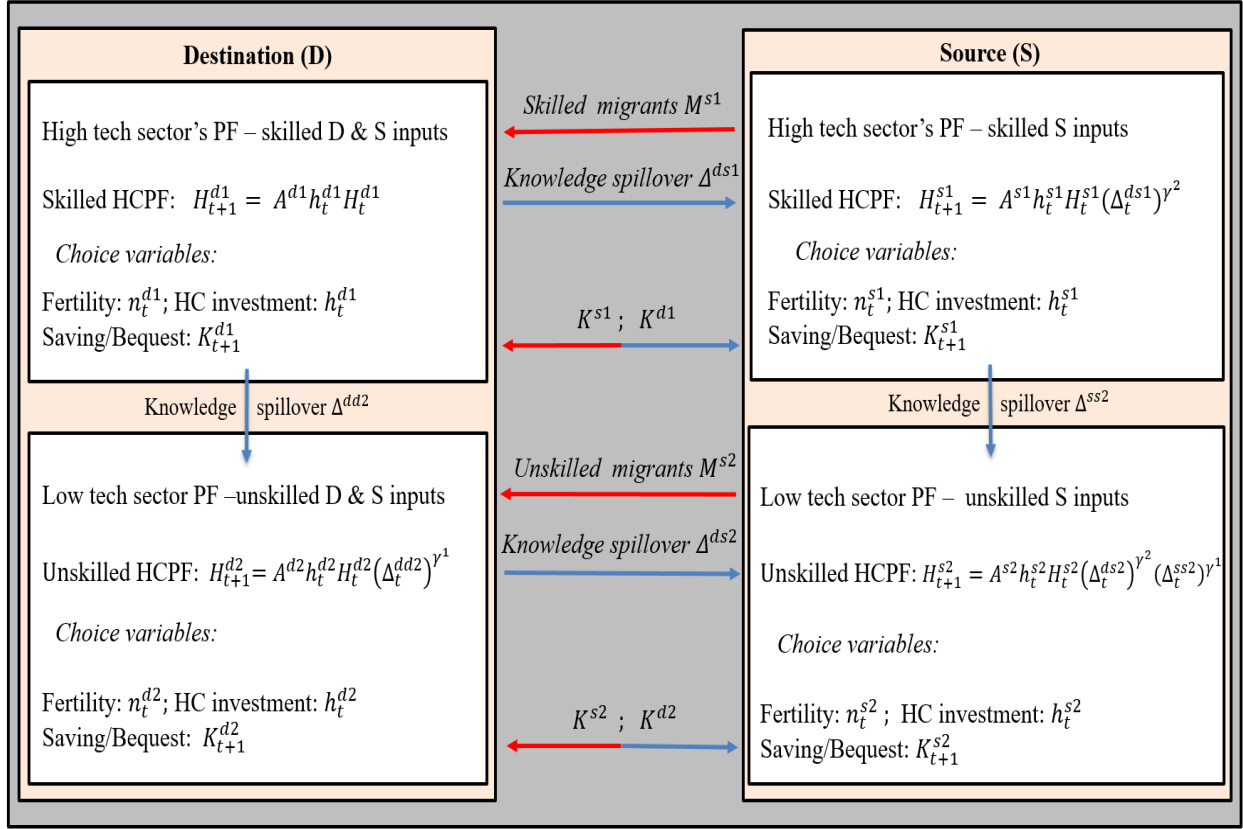
**Figure 10. The Short-Term Immigration Surplus**



Pre-migration gross domestic product:	$A+B+C$
Post-migration gross domestic product:	$A+B+C+D+E$
Pre-migration natives' labor income:	$B+C$
Post-migration natives' labor income:	$C+E$
Immigrants (M) labor income:	$D$
Pre-migration natives' return on capital:	$A$
Post-migration natives' return on capital:	$A+B+E$
Immigration Surplus:	$E$

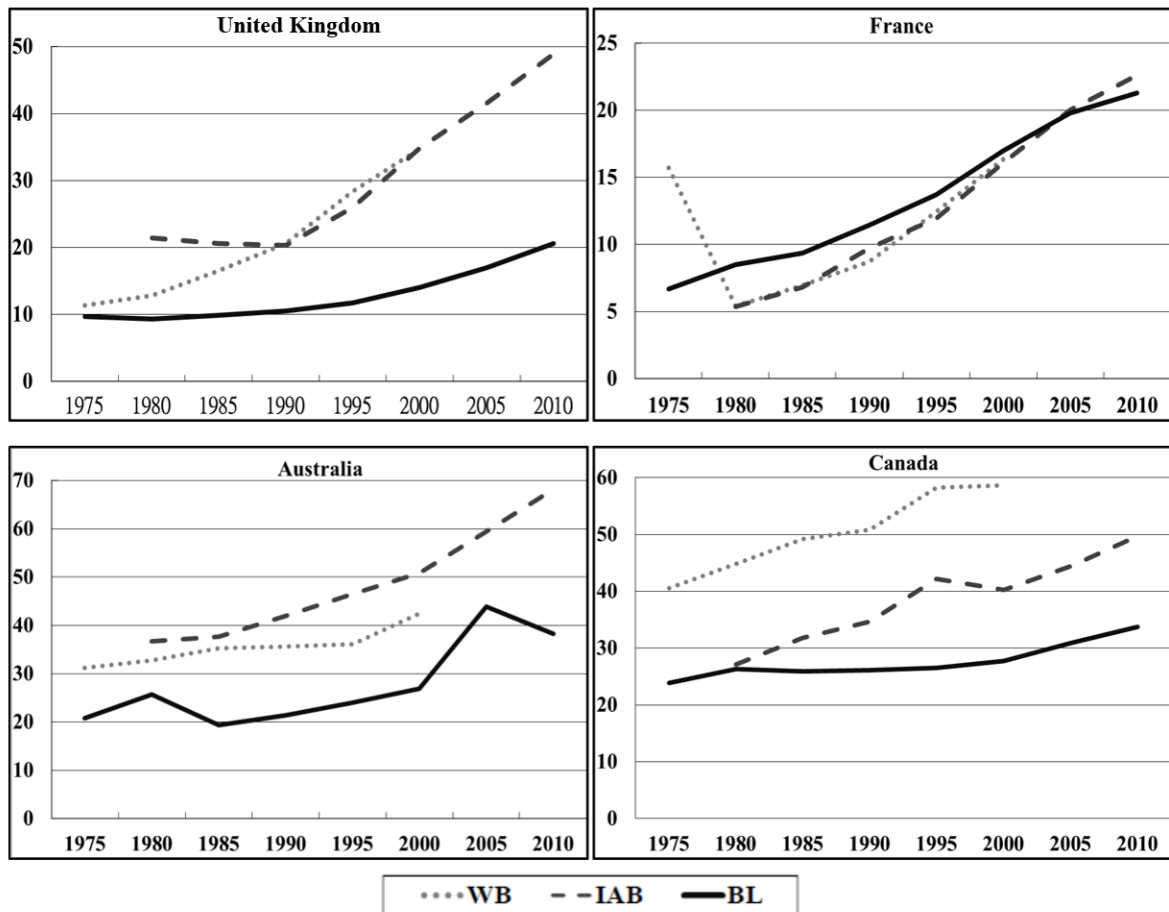
Notes: The recent National Academy of Sciences Report on the economic and fiscal consequences of immigration (see NAS, 2017) has estimated the immigration surplus in the United States to be 0.3% of its gross domestic product, which amounts to \$54.2 billion.

**Figure 11. Equilibrium Migration with Hierarchical and Gravitational Spillover Effects:  
A Global View**



Notes: HC = human capital; HCPF = human capital production function; PF = production function.

**Figure 12. Weighted averages of the skill composition of the migrant population (WB=World Bank; IAB=Institute for Labor Research) vs. total domestic population (BL=Barro and Lee) in major destination countries: population age 25+ with 13+ years of education**



Source: WB data are from Schiff and Sjolom (2011). IAB data are from Brücker, Capuano, and Marfouk (2013). BL data are from Barro and Lee (2013).



**Table 1. Comparative Dynamics under the Benchmark Model**

Parameter Shift	$n^{d1}$ $= n^{d2}$	$n^{s1}$ $= n^{s2}$	$n^{m1}$ $= n^{m2}$	$h^{d1}$ $= h^{d2}$	$h^{s1}$ $= h^{s2}$	$h^{m1}$ $= h^{m2}$	$H_{t+1}^{ij}/H_t^{ij}$ $= K_{t+1}^{ij}/K_t^{ij}$	$\Delta^{dd2}$ $= \Delta^{ss2}$	$\Delta^{ds1}$ $= \Delta^{ds2}$	$M^{s1}/$ $(M^{s1}+M^{s2})$
1. Benchmark	0.9561	1.5530	1.2045	0.2969	0.1858	0.1858	2.9693	5.6569	5.6386	0.5
2. $A^{d1} = 12, A^{s1} = 9.6$	0.9630	1.5657	1.2155	0.2969	0.1858	0.1858	3.5632	8.9234	5.6386	0.5182
3. $v^d = 0.1705$	0.8645	1.5596	1.1939	0.3266	0.1858	0.1858	3.2663	5.6569	7.1558	0.5
4. $\Gamma^{s1} = \Gamma^{s2} = 8.404$	0.9591	1.5530	1.2059	0.2969	0.1858	0.1858	2.9693	5.6569	5.6386	0.5

Parameter Shift	$M^{s1}/N^{d1}$ $= M^{s2}/N^{d2}$	$M^{s1}/N^{s1}$ $= M^{s2}/N^{s2}$	$K^{d1}/H^{d1}$ $= K^{d2}/H^{d2}$	$K^{s1}/H^{s1}$ $= K^{s2}/H^{s2}$	$H^{d1}/H^{s1}$ $= H^{d2}/H^{s2}$	$K^{d1}/K^{s1}$ $= K^{d2}/K^{s2}$	$w^{d1}/w^{s1}$ $= w^{d2}/w^{s2}$	$r^{d1}/r^{s1}$ $= r^{d2}/r^{s2}$	$H^{d1}/H^{d2}$ $= H^{s1}/H^{s2}$	$K^{d1}/K^{d2}$ $= K^{s1}/K^{s2}$
1. Benchmark	0.1517	0.2667	0.3230	0.1283	2.2004	5.5389	1.5753	0.6741	5.6569	5.6569
2. $A^{d1} = 12, A^{s1} = 9.6$	0.1780	0.2467	0.2472	0.0980	2.8863	7.2831	1.5791	0.6708	8.9234	8.9234
3. $v^d = 0.1705$	0.2878	0.2254	0.3256	0.1114	6.7921	19.8442	1.6622	0.6055	5.6569	5.6569
4. $\Gamma^{s1} = \Gamma^{s2} = 8.404$	0.0888	0.3135	0.3209	0.1278	1.0072	2.5280	1.5708	0.6828	5.6569	5.6569

Benchmark parameters:  $\sigma = 0.9$ ,  $\delta = 0.7$ ,  $B = 1$ ,  $\beta = 1.3$ ,  $\alpha = 1/3$ ,  $\eta = 2/3$ ,  $\gamma^1 = \gamma^2 = 0.4$ ,  $\Gamma^{d1} = \Gamma^{d2} = 10$ ,  $\Gamma^{s1} = \Gamma^{s2} = 8.424$ ,  $A^{d1} = 10$ ,  $A^{d2} = 5$ ,  $A^{s1} = 8$ ,  $A^{s2} = 4$ ,  $\theta^{d1} = \theta^{d2} = \theta^{s1} = \theta^{s2} = 1.16$ ,  $v^d = 0.155$ ,  $v^s = 0.097$ ,  $\tau^{h1} = \tau^{h2} = 0.052$ ,  $\tau^{k1} = \tau^{k2} = 0.5$ .

**Table 2. Benchmark Model: Immigration Surplus Changes due to Induced Migration by Triggers**

Trigger	Destination <i>D</i>			Source <i>S</i>
	3rd generation after a shock	5th generation after a shock	10th generation after a shock	10th generation after a shock
<b>1. Skill-biased technological shock in D and S</b>				
Human capital	0.04	0.25	1.16	-14.18
Physical capital	0.06	0.25	1.10	-13.98
Full income	0.05	0.26	1.14	-14.11
Utility	0.007	0.04	0.23	-2.30
<b>2. Adverse fertility shock in D</b>				
Human capital	0	0	0	67.96
Physical capital	-0.20	-0.50	-1.29	54.48
Full income	-0.16	-0.35	-0.77	64.03
Utility	-0.004	-0.01	-0.03	10.76
<b>3. Adverse productivity shock in S</b>				
Human capital	0	0	0	40.39
Physical capital	-0.08	-0.26	-0.42	37.99
Full income	-0.10	-0.16	-0.24	39.61
Utility	-0.001	-0.005	-0.009	5.01

Notes: Values are percentage changes in welfare measures. Positive values mean loss from restricting migration, hence gain from unrestricted migration.

**Table 3. Extended Model: Immigration Surplus Changes due to Induced Migration by Triggers**

Trigger	Destination <i>D</i>			Source <i>S</i>
	3rd generation after a shock	5th generation after a shock	10th generation after a shock	10th generation after a shock
<b>1. Skill-biased technological shock in D and S</b>				
Human capital	0.01	0.21	1.35	-13.99
Physical capital	0.05	0.22	1.17	-14.43
Full income	0.03	0.22	1.28	-14.12
Utility	0.004	0.04	0.25	-2.40
<b>2. Adverse fertility shock in D</b>				
Human capital	0.36	1.20	5.15	71.48
Physical capital	-0.12	0.06	2.51	58.20
Full income	0.10	0.63	3.95	67.66
Utility	0.04	0.11	0.50	11.79
<b>3. Adverse productivity shock in S</b>				
Human capital	0.40	-0.08	-2.65	39.33
Physical capital	0.70	0.13	-2.21	37.27
Full income	0.40	-0.09	-2.61	38.65
Utility	0.05	-0.01	-0.27	4.84

Notes: Values are percentage changes in welfare measures. Positive values mean loss from restricting migration, hence gain from unrestricted migration.