

The Reverse-Flow of Human Capital and Reindustrialization

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Abstract: This paper constructs a two-sector model including manufacturing and services, and studies the influence of cross-sector forward-flow and reverse-flow of human capital on economic structure change, deindustrialization and reindustrialization. The two sectors accumulate human capital independently, while human capital migrates between sectors. This paper analyzes the condition of human capital reverse-flow in equilibrium. The conclusion is that the forward-flow of human capital from manufacturing to services will lead to the decline of the share of manufacturing output and the accelerated increase of the share of services output, which will lead to the trend of deindustrialization; whereas the reverse-flow of human capital from services to manufacturing will lead to the revival of the share of manufacturing output and the decelerated increase of the share of services output, which will lead to the trend of reindustrialization. The forward-flow and reverse-flow of human capital is the fundamental reason for the trend of deindustrialization and reindustrialization.

Keywords: Human Capital; Forward-Flow; Reverse-Flow; Deindustrialization; Reindustrialization

1. Introduction

Human capital is a key driving force of modern economic growth. The cross-sector flow of human capital not only affects the efficiency of human capital accumulation, but also has a fundamental impact on the relative economic status of the sector. Therefore, human capital has become an important driving factor of structural change. Not only that, under certain conditions, the reverse flow of human capital will occur. This kind of complex flow mode will not only bring more changes to sectoral growth and structural change, but also have a direct and crucial impact on the process of deindustrialization and reindustrialization

which are prevalent in developed economies.

A growing body of academic research has emerged on human capital return migration, yielding fruitful results. The first strand of literature examines the relationship between human capital return migration and reverse entrepreneurial migration, finding that states can promote overseas talent to return and start businesses through institutional arrangements [1]; that return migrants bring human capital accumulated abroad back to their home countries, generating positive externalities for home-country economic growth [2]; and that quantitative assessments of the causal effects of national talent attraction policies on scholars' return decisions and research productivity have identified research funding support and professional title preferences as the most pivotal drivers of return migration [3]. Furthermore, this literature distinguishes between full-time and part-time return migration modes by analyzing government policies for attracting overseas talent return as well as domestic resistance to such policies, exploring how states can maximize the dividends of returned human capital [4].

The second strand of literature analyzes the geographic and spatial distribution of high-level talent returning to China, identifying innovation environments, quality of life, and industrial policies as the core factors attracting returnees [5]; reveals the spatial pattern whereby returned talent primarily agglomerates in first-tier cities and innovation hubs along the eastern coast [6]; and confirms that return migration serves as a core mechanism reshaping the global spatial allocation of human capital [7].

The third strand of literature analyzes the relationship between brain circulation and human capital networks, proposing the concepts of "brain circulation" and "brain linkage." It argues that, compared with traditional talent return migration models, transnational human capital networks allow overseas talent to contribute knowledge capital to their home countries through transnational linkages without

fully returning home [8]; subsequently, this literature systematically traces the emerging trends in China's transnational talent mobility, from the evolution of brain drain and brain gain to brain circulation, revealing that human capital return migration in the era of globalization is no longer a one-way permanent migration but a dynamic, cyclical process [9].

The fourth strand of literature analyzes home-country pull factors and return migration decisions, finding that home-country economic growth, family ties, and collectivist cultural drives are important pull factors that promote return migration [10], and emphasizes the pivotal role of human capital and social capital brought back by returnees in reverse migration for home-country development [11].

The fifth strand of literature analyzes the relationship between human capital return migration and structural transformation, arguing that return migration serves as a key mechanism integrated into the structural transformation process [12]; maintains that the capital brought back by high-skilled immigrants has catalyzed structural change in the home country [13]; clarifies the dual transmission paths of skill spillovers and overseas social networks [14]; and systematically reviews the interactive mechanisms through which family ties, public policy, and macro-level structural transformation jointly influence return migration decisions [15].

Another strand of literature analyzes the relationship between human capital return migration and reindustrialization from a tangential perspective, arguing that reindustrialization requires not only the return of capital but also industrial workers with specific skill combinations [16]; analyzes how transnational "brain circulation" networks promote regional upgrading of specific industries in home countries through technology transfer and knowledge spillovers [17]; and proposes multi-pronged approaches to revitalizing America's industrial heartland, emphasizing that reindustrialization entails not merely the reshoring of industrial chains but also the cultivation and agglomeration of skilled talent, thereby corroborating from a tangential perspective that human capital is a core element of reindustrialization [18].

Existing literature lacks direct analysis of the relationship between human capital return migration and reindustrialization. The

upgrading of industrial structure is very important to the improvement of economic efficiency of a country, moreover, the recent industrial transformation of major developed economies has experienced new changes. Because the early deindustrialization process failed to stimulate economic growth, the developed economies generally implemented the strategy of reindustrialization. Figure 1 shows the trend of deindustrialization and reindustrialization of the United States in recent years.

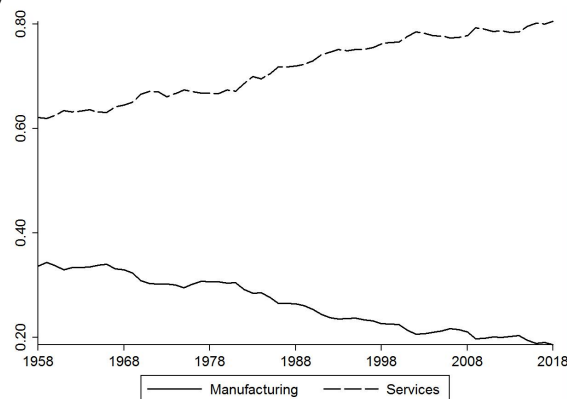


Figure 1. U.S. Output Shares, 1958–2018

This paper holds that the trend of deindustrialization and reindustrialization is closely related to the forward-flow and reverse-flow of human capital between manufacturing and services. The forward-flow of human capital from manufacturing to services will make the talents in services abundant and the talents in manufacturing short. This will increase the growth rate and output share of services and reduce the growth rate and output share of manufacturing, thus forming the trend of deindustrialization. The reverse-flow of human capital from services to manufacturing will reduce the human capital of services and increase the human capital of manufacturing, which will slow down the growth of output share of services and enhance the output share of manufacturing, thus forming the trend of reindustrialization. Therefore, it is of great significance to analyze the formation mechanism and influence effect of the reverse-flow of human capital in the structural change process.

This paper constructs a two-sector economic growth model including manufacturing and services. Each sector accumulates human capital separately, and human capital migration is affected by migration cost and sectoral human capital gap. Based on this, this paper

sets up the dynamic equations of human capital accumulation and human capital migration, and derives the human capital migration rate in equilibrium. This paper further obtains the formation conditions of the forward-flow and reverse-flow of human capital, and analyzes the impact of the forward-flow and reverse-flow of human capital on sectoral human capital accumulation, the growth of the sectoral and the aggregate economy, and analyzes the characteristics of the changes in the output share of manufacturing and services, as well as the formation mechanism of deindustrialization and reindustrialization under the conditions of the forward-flow and reverse-flow of human capital.

The main contribution of this paper is to make a beneficial attempt at the mechanism of human capital reverse-flow and the formation mechanism of deindustrialization and reindustrialization which can not be systematically analyzed in the existing literature, and to get some more explanatory conclusions. The basic conclusion of this paper is that the flow direction of human capital depends on the positive and negative value of the product of two complex terms related to sectoral wages. When the product of two terms is negative, human capital flows forward from the manufacturing into the services, which leads to a gentle decline in the share of manufacturing output and an accelerated rise in the share of services output, thus forming a trend of deindustrialization; whereas when the product of two terms is positive, human capital flows back to the manufacturing from the services in reverse, which leads to the recovery of the share of manufacturing output and an decelerated rise in the share of services output, thus forming the trend of reindustrialization. The flow of human capital will lead to the change of sectoral wages, and the change of sectoral wages will cause the product of the two terms to change alternately between positive and negative values, thus the flow direction of human capital will continue to cycle and change alternately between forward-flow and reverse-flow. The forward-flow and reverse-flow of human capital is the fundamental reason for the structural change and the trend of deindustrialization and reindustrialization.

This article is organized as follows. The second section describes the economic structure of the product market; the third section describes the

dynamic process of human capital migration; the fourth section analyzes the conditions of the forward-flow and reverse-flow of human capital in equilibrium, and analyzes the influencing factors of the threshold value of human capital reverse-flow; the fifth section investigates the influence of the forward-flow and reverse-flow of human capital on sectoral human capital accumulation, sectoral and aggregate economic growth, and analyzes the formation mechanism of deindustrialization and reindustrialization; the sixth section summarizes the full text.

2. Product Market

In the baseline model, we establish an economic system includes two sectors, the commodity sector and the service sector, represented by M and S , respectively. The commodity sector and the service sector independently engage in good production. The production function of the goods of the two sectors as follows:

$$Y_M = A_M H_{Y_M}, Y_S = A_S H_{Y_S} \quad (1)$$

where Y_M and Y_S are goods produced by the commodity sector and the service sector, respectively, and H_{Y_M} and H_{Y_S} are the amounts of human capital invested in the production process by the two sectors, respectively. A_M and A_S indicate the technology levels of the two sectors. We also make a simple assumption about technological advances: technological advances in both sectors are exogenous with a rate of technological progress of $g_A = 0$ ($i = M, S$). The prices of goods in the two sectors are P_i , the actual gains of human capital are w_i , and the nominal gains of human capital are $W_i = w_i P_i$ ($i = M, S$).

The final good is a combination of the goods from both the commodity sector and the service sector, taking the following form:

$$Y = Y_S^\alpha Y_M^\beta \quad (2)$$

where Y is the output of the final good. α and $\beta = 1 - \alpha$ are shares of the output of the two sectors in the production process of the final good, representing the importance of the outputs of the two sectors in the production of the final good, meeting $\alpha \in (0, 1)$.

Given the economy's production structure, the nominal wages of the two sectors are then obtained as

$$W_M = P_M A_M = \beta \frac{Y}{H_{Y_M}}, W_S = P_S A_S = \alpha \frac{Y}{H_{Y_S}} \quad (3)$$

Further, the sectoral relative wage ratio, namely, the sectoral wage gap is:

$$\frac{W_S}{W_M} = \frac{P_S A_S}{P_M A_M} = \frac{\alpha}{\beta} \frac{H_{Y_M}}{H_{Y_S}} \quad (4)$$

Eq. (4) implies that the sectoral wage gap is positively correlated with the sectoral technology gap, and is negatively correlated with relative employment in production sectors. The utility function of the representative household is as follows:

$$U = \int_0^\infty \frac{C^{1-\theta} - 1}{1-\theta} e^{-\rho t} dt \quad (5)$$

where $\rho > 0$ is the subjective time preference rate, $\theta > 0$ is the reciprocal of the intertemporal elasticity of substitution.

3. The Dynamics of Human Capital

The dynamics of human capital includes two aspects: the human capital accumulation and the human capital migration. Human capital accumulation is the main process by which a sector acquires new human capital; whereas, the reallocating effect of the cross-sector dynamic migration process of human capital on the amount of regional human capital cannot be ignored.

Human capital migration has a reallocation effect on the sectoral human capital stock. The sectoral human capital includes two parts. One is non-migrant human capital, which is mainly formed by the accumulation of the sector itself and is fixed in the sector without cross-sector migration. The other part is the human capital gained or lost by human capital migration. The relationships between sectoral human capital, migrant human capital and non-migrant human capital can be expressed as follows:

$$\bar{H}_M = H_M + H_F, \bar{H}_S = H_S - H_F \quad (6)$$

where $\bar{H}_M$ and $\bar{H}_S$ are the sectoral human capital in manufacturing and services, respectively; and H_M and H_S are the amounts of non-migrant human capital in the two sectors, and H_F is migrant human capital.

3.1 Human Capital Accumulation

Given that human capital migration is primarily reflected in changes in the quantity of human capital, to maintain the unity of the concept of human capital within the framework of a model, the investigation into human capital accumulation also focuses on the characterization of the increase in human

capital stock. This implies that human capital is homogeneous in this paper, and human capital accumulation refers to the increase in the number of individuals with high skills. In these settings, the job-search issue resulting from the heterogeneity of human capital is discarded, the complex influence of human capital externality on human capital accumulation and human capital migration has also been abandoned, and the role of human capital migration in quantitative change can be understood.

Because this study focuses on the dynamic migration process of human capital, the human capital accumulation process is further simplified. Assuming human capital accumulation in two sectors is only limited by their respective amounts of human capital input while ignoring the labor time and inputs of other resources expended in the human capital accumulation process, the higher the amount of human capital investment in a sector, the more advantages the sector has in nurturing human capital. The human capital accumulation processes of manufacturing and services can be described as follows:

$$\dot{H}_M = d_M H_{H_M}, \dot{H}_S = d_S H_{H_S} \quad (7)$$

where $d_M, d_S > 0$ is the efficiency parameter of human capital accumulation. $\dot{H}_M$ and $\dot{H}_S$ represent the sectoral new human capital amounts produced by human capital accumulation. H_{H_D} and H_{H_L} represent the sectoral amounts of investment in human capital during the process of accumulating human capital. Human capital market clearing of the two sectors require that:

$$\bar{H}_M = H_{Y_M} + H_{H_M}, \bar{H}_S = H_{Y_S} + H_{H_S} \quad (8)$$

Furthermore, assuming the ratios of human capital invested during the human capital accumulation process to the sectoral human capital are u_M and u_S , then human capital market clearing can be rewritten as:

$$H_{H_M} = u_M \bar{H}_M = u_M (H_M + H_F) \quad (9)$$

$$H_{Y_M} = (1 - u_M) \bar{H}_M = (1 - u_M) (H_M + H_F) \quad (10)$$

$$H_{H_S} = u_S \bar{H}_S = u_S (H_S + H_F) \quad (11)$$

$$H_{Y_S} = (1 - u_S) \bar{H}_S = (1 - u_S) (H_S + H_F) \quad (12)$$

The immigration of human capital into the developed region can increase the amount of regional human capital, generating a positive output effect. The emigration of human capital from the less-developed region can reduce the amount of regional human capital, generating a

negative output effect.

3.2 Human Capital Migration Dynamics

Cross-sector human capital migration is a dynamic process, during which the factors of production are reallocated among sectors, leading to dynamic changes in sectoral economic growth rates and in their relative importance throughout the economic system.

Services is an advanced sector with rapid development in the economy, full of vigor and vitality, which represents the direction of future industrial development. Services needs to invest a lot of human capital in the development process; while manufacturing is a medium speed development sector in the economy, the development of manufacturing mainly depends on technological innovation and the investment of machinery and equipment, and the demand for human capital in manufacturing is relatively small. Thus we can assume that human capital flows from manufacturing to services. Because the production structure of the model is completely symmetrical, this assumption will not only not affect the model analysis, but also facilitate us to derive the conditions of the reverse-flow of human capital.

Note that both wages and the productivity of human capital in manufacturing are relatively low and those in services are relatively high, if wages in manufacturing cannot be increased to match services, then human capital will tend to migrate into services. That is, sectoral wage difference is the benefits of human capital migration, which is the main driving force of human capital migration. The reversal of the migration direction of human capital involves a complex condition of sectoral wage difference, which will be analyzed below.

Next, this paper examines the factors that influence the dynamic process of human capital migration.

First, migration costs rise in the process of interregional human capital migration. The economic costs primarily include spending on overcoming institutional barriers, housing and other resettlement costs and relocation costs, etc. Noneconomic costs include the costs of rebuilding interpersonal relationships, losses in welfare such as the original social security in the previous area, the inconvenience to family life, etc. In this study, these costs are generally regarded as the social resources expended in the migration process. The consumption of social

resources in migration will affect the constraints of social resources and lead to the reduction of consumption.

Second, the sectoral human capital gap is expressed as the human capital ratio of manufacturing and services, which has an important impact on human capital migration. The sectoral human capital gap indicates the sectoral relative employment, which represents the supply and demand of migrant human capital between sectors. The employment of human capital immigrant sector (services) represents the demand of migrant human capital, while the employment of human capital emigrant sector (manufacturing) represents the supply of migrant human capital. In the case of continuous human capital migration, if the human capital gap between services and manufacturing expands, it means that the demand for migrant human capital is higher than its supply, and the migration of human capital will have an accelerated trend; whereas, if the sectoral human capital gap is narrowed, it means that the supply of migrant human capital is higher than its demand, and the migration of human capital will slow down. As a result, the human capital gap has a direct impact on human capital migration.

Cross-sector human capital flow is a continuous and dynamic process. The quantity of instantaneous human capital migration can be calculated by adding all of the human capital from manufacturing to services at a given point in time. Therefore, the dynamic process of human capital migration can be expressed as follows:

$$\dot{H}_F = d_F Z_F h^y \quad (13)$$

where $d_F > 0$ is the parameter to characterize the efficiency of human capital migration. Z_F represents the amount of instantaneous costs associated with human capital migration. $h = H_S / H_M$ shows the influence of the sectoral human capital gap on human capital migration, and the impact is portrayed by y , which satisfies $1 - a > y > 0.5 - a$. Furthermore, $h_M = H_F / H_M$ and $h_S = H_F / H_S$ represent the ratios of the migrant human capital to the non-migrant human capital in the two sectors, measuring the effect of human capital migration on human capital accumulation in the two sectors.

Because this study focuses on describing the

economic effects of the migration of human capital, the category of human capital is examined from the quantitative perspective. The accumulation and the migration of human capital are both quantitative change processes of human capital. Accordingly, in this study, human capital is implicitly added to the homogeneous assumptions that services does not erect a barrier to human capital migration. The employment and migration of human capital in the two sectors are due to the needs of sectoral production, and have nothing to do with the quality of human capital.

The costs of human capital migration can be expressed as:

$$Z_F = z_F Y \quad (14)$$

where $z_F > 0$ is the costs consumed by human capital migration as a proportion of total social resources.

Total social goods are primarily used to pay the costs of human capital migration and total social consumption. The resource constraints of the aggregate economy can be expressed as follows:

$$C + Z_F \leq Y \quad (15)$$

4. Sectoral Economic Equilibrium

With a continuous cross-sectoral flow of human capital, economic resources are reallocated among sectors and as a result, the two sectoral economies gradually achieve the BGP equilibrium. When sectoral economies achieve equilibrium, the aggregate economy also achieves dynamic equilibrium. The current-value Hamiltonian is constructed as follows:

$$H = \ln C + \lambda_{HM} \dot{H}_M + \lambda_{HS} \dot{H}_S + \lambda_{HF} \dot{H}_F \quad (16)$$

s.t. $C = (1 - z_F)[A_S(1 - u_S)\bar{H}_S]^a [A_M(1 - u_M)\bar{H}_M]^b$ where C , u_M , u_S and z_F are control variables; H_M , H_S and H_F are state variables; λ_{HM} , λ_{HS} and λ_{HF} are Hamilton multipliers; $\dot{H}_M$, $\dot{H}_S$ and $\dot{H}_F$ are shown in Eqs.(7) and (13) and constrained by Eqs.(9)~(12) and (14). By solving this Hamiltonian system, we see that the main characteristics of both the sectoral economy and the aggregate economy are on the equilibrium growth path.

Sectoral economic equilibrium is defined as the allocation in which the human capital markets in both sectors clear and consumers achieve intertemporal optimization. The sectoral balanced growth path (SBGP) is the locus of such sectoral equilibrium allocations along

which the sectoral growth rate remains constant. Aggregate economic equilibrium, analogously, requires that human capital markets across all sectors clear and that aggregate consumption is intertemporally optimized. The aggregate balanced growth path (ABGP) traces out these aggregate equilibrium allocations, characterized by a constant growth rate of the aggregate economy. Solving the present-value Hamiltonian in Eq. (14) yields the growth rates of the key variables along both the SBGP and the ABGP.

4.1 Equilibrium Human Capital Migration

By solving the Hamiltonian system shown in Eq. (16), the equilibrium human-capital migration rate can be obtained as shown in the following proposition.

Proposition 1: In the human capital reverse-flow model, manufacturing and services each admit a unique sectoral balanced growth path (SBGP) equilibrium. When both sectors are on their respective SBGPs, the aggregate economy also lies on the aggregate balanced growth path (ABGP). Moreover, the human capital migration rate satisfying the equilibrium conditions of both the ABGP and the RBGP is the equilibrium human capital migration rate, characterized by the following equation:

$$g_{H_F} = \frac{[\theta \delta_F \eta'' (W_S - W_M) - \rho] - (\theta - 1)[\alpha \delta_S + \beta \delta_M]}{\theta + \frac{\psi(\theta - 1)}{\delta_F \eta''} \left[\frac{\alpha \eta_S \delta_S}{W_S} - \frac{\beta \eta_M \delta_M}{W_M} \right]} \quad (17)$$

Proposition 1 reveals that human capital migration shapes both sectoral human capital accumulation and sectoral economic growth. The equilibrium migration rate plays a dual role: first, it ensures that each sectoral economy converges to its own sectoral balanced growth path (SBGP); second, by closely linking the two interdependent sectors, it enables the aggregate economy to attain the ABGP equilibrium. Therefore, the equilibrium human capital migration rate is fully consistent with both the SBGP and the ABGP equilibrium conditions.

4.2 The Forward-Flow and Reverse-Flow of Human Capital

In the process of cross-sector human capital reallocation, not only the forward flow of human capital from manufacturing to services, but also the reverse flow from services to manufacturing will occur. It is very important to analyze the conditions of the reverse-flow of human capital. The following propositions can

be obtained by examining Eq.(17):

Proposition 2: In the human capital reverse-flow model, if

$$\left[(W_S - W_M) - \frac{(\theta - 1)(\alpha\delta_S + \beta\delta_M) + \rho}{\theta\delta_F\eta^\psi} \right] \left[\frac{\beta\eta_M\delta_M}{W_M} - \frac{\alpha\eta_S\delta_S}{W_S} - \frac{\theta\delta_F\eta^\psi}{\psi(\theta - 1)} \right] < 0 \quad (18)$$

then $g_{H_F} > 0$, human capital flows from manufacturing to services; and if

$$\left[(W_S - W_M) - \frac{(\theta - 1)(\alpha\delta_S + \beta\delta_M) + \rho}{\theta\delta_F\eta^\psi} \right] \left[\frac{\beta\eta_M\delta_M}{W_M} - \frac{\alpha\eta_S\delta_S}{W_S} - \frac{\theta\delta_F\eta^\psi}{\psi(\theta - 1)} \right] \geq 0 \quad (19)$$

then $g_{H_F} \leq 0$, human capital flows reversely from services to manufacturing.

Proposition 2 shows that the migration direction of human capital depends on the positive and negative sign of the product of the two terms.

Term $(W_S - W_M) - \frac{(\theta - 1)(\alpha\delta_S + \beta\delta_M) + \rho}{\theta\delta_F\eta^\psi}$ gives

the conditions to be satisfied when the direction of human capital migration is reversed.

When other conditions remain unchanged, if the sectoral wage difference $(W_S - W_M)$ is higher or lower than the threshold $\frac{(\theta - 1)(\alpha\delta_S + \beta\delta_M) + \rho}{\theta\delta_F\eta^\psi}$, it

will trigger the reversal of the direction of human capital flow.

Sectoral wage difference is the benefits of the migration process. When the sectoral wage difference is higher than the threshold value, it is profitable for human capital to move from manufacturing to services; when the sectoral wage difference is lower than the threshold value, human capital will move back from services to manufacturing.

In addition, there is another mechanism that will lead to the reversal of the direction of human capital migration.

In the process of migration, the ratio of migrated human capital to non-migrated human capital will change, which represents the relative demand intensity of sectoral production for migrated human capital and non-migrated human capital. When the ratio changes, wages will also change accordingly, resulting in the change of item $\frac{\beta\eta_M\delta_M}{W_M} - \frac{\alpha\eta_S\delta_S}{W_S} - \frac{\theta\delta_F\eta^\psi}{\psi(\theta - 1)}$ and

affecting the direction of human capital migration.

An increase in the ratio of migrated human

capital and non-migrated human capital, η_M and η_S , shows that the development of services has higher demand for migrated human capital, and the wages of services are also higher, whereas manufacturing has lower wages and relatively more non migrated human capital is employed. At this time,

$\frac{\beta\eta_M\delta_M}{W_M} - \frac{\alpha\eta_S\delta_S}{W_S} - \frac{\theta\delta_F\eta^\psi}{\psi(\theta - 1)} < 0$, human capital will

migrate from manufacturing to services.

A decrease in the ratio of migrated human capital and non migrated human capital, η_M and η_S , shows that the employment of services to the migrated human capital decreases, and the wages of services also have a downward trend, whereas the human capital emigration of manufacturing has declined. At this time,

$\frac{\beta\eta_M\delta_M}{W_M} - \frac{\alpha\eta_S\delta_S}{W_S} - \frac{\theta\delta_F\eta^\psi}{\psi(\theta - 1)} > 0$, there is a reverse

migration of human capital from the services to the manufacturing industry.

4.3 The Process of Human Capital Flow

The forward- and reverse-flow of human capital depends on the signs of terms $(W_S - W_M) - \frac{(\theta - 1)(\alpha\delta_S + \beta\delta_M) + \rho}{\theta\delta_F\eta^\psi}$ and $\frac{\beta\eta_M\delta_M}{W_M} - \frac{\alpha\eta_S\delta_S}{W_S} - \frac{\theta\delta_F\eta^\psi}{\psi(\theta - 1)}$.

First, when $\frac{\beta\eta_M\delta_M}{W_M} - \frac{\alpha\eta_S\delta_S}{W_S} - \frac{\theta\delta_F\eta^\psi}{\psi(\theta - 1)} < 0$, the

sectoral wage difference $(W_S - W_M)$ is higher than the threshold $\frac{(\theta - 1)(\alpha\delta_S + \beta\delta_M) + \rho}{\theta\delta_F\eta^\psi}$, the

higher wage can be obtained by moving from the manufacturing to the services, and the condition Eq.(18) is met, at this time, the human capital migration from the manufacturing to the services will occur. The migration of human capital results in the increase of human capital stock in services and the decrease of human capital stock in manufacturing, the decrease of wages in services and the increase of wages in manufacturing, and the decrease of the sectoral wage difference. Whereas this also leads to an increase in the ratio of migrated human capital to non-migrated human capital, so term $\frac{\beta\eta_M\delta_M}{W_M} - \frac{\alpha\eta_S\delta_S}{W_S} - \frac{\theta\delta_F\eta^\psi}{\psi(\theta - 1)}$ is still negative. When

the sectoral wage difference $(W_S - W_M)$ is lower

than the threshold $\frac{(\theta-1)(\alpha\delta_S + \beta\delta_M) + \rho}{\theta\delta_F\eta^\psi}$, and

the condition Eq.(19) is satisfied, the direction of human capital migration will be reversed, and human capital will move from services to manufacturing in reverse. The reverse migration of human capital results in the increase of human capital stock in manufacturing, the decrease of human capital stock in services, the decrease of wages in manufacturing and the increase of wages in services. Whereas this also leads to a decrease in the ratio of migrated human capital to non-migrated human capital, which will cause term

$\frac{\beta\eta_M\delta_M}{W_M} - \frac{\alpha\eta_S\delta_S}{W_S} - \frac{\theta\delta_F\eta^\psi}{\psi(\theta-1)}$ to change from

negative value to positive value. At this time, condition Eq.(18) is satisfied again, and human capital migration will change from reverse migration to forward migration.

Then, when $\frac{\beta\eta_M\delta_M}{W_M} - \frac{\alpha\eta_S\delta_S}{W_S} - \frac{\theta\delta_F\eta^\psi}{\psi(\theta-1)} > 0$, the

sectoral wage difference $(W_S - W_M)$ is lower than threshold $\frac{(\theta-1)(\alpha\delta_S + \beta\delta_M) + \rho}{\theta\delta_F\eta^\psi}$, and

condition Eq.(18) is satisfied, the forward-migration from manufacturing to services occurs. The wages of services decreased while the wages of manufacturing increased, and the sectoral wage difference decreased; and there is an increase in the ratio of migrated human capital to non-migrated human capital, and term $\frac{\beta\eta_M\delta_M}{W_M} - \frac{\alpha\eta_S\delta_S}{W_S} - \frac{\theta\delta_F\eta^\psi}{\psi(\theta-1)}$ gradually changed

from positive to negative, whereas, the sectoral wage difference $(W_S - W_M)$ is still lower than the threshold, and the condition Eq. (19) is met. The direction of human capital migration is reversed, and human capital migrates reversely from services to manufacturing. The reverse-migration of human capital results in the decrease of manufacturing wage and the rise of service wage, and the sectoral wage difference $(W_S - W_M)$ gradually becomes higher than the threshold. At this time, the condition Eq.(18) is satisfied again, and the direction of human capital migration changes from reverse to forward.

In this way, under the influence of terms $(W_S - W_M) - \frac{(\theta-1)(\alpha\delta_S + \beta\delta_M) + \rho}{\theta\delta_F\eta^\psi}$ and

$\frac{\beta\eta_M\delta_M}{W_M} - \frac{\alpha\eta_S\delta_S}{W_S} - \frac{\theta\delta_F\eta^\psi}{\psi(\theta-1)}$, the migration

direction of human capital is in the cycle between forward flow and reverse flow, which has a direct impact on sectoral human capital accumulation, sectoral economic growth and structural change.

5. Economic Growth and Structural Change

5.1 Sectoral Human Capital Accumulation

Solving the Hamiltonian shown in Eq.(16), we obtain the equilibrium human capital accumulation rates of the two sectors, as shown in the following proposition.

Proposition 3: In the human capital reverse-flow model, when services and manufacturing both lie on their respective SBGPs, sectoral human capital accumulation also attains equilibrium. The equilibrium human-capital accumulation rates along the two sectors' SBGPs are given by:

$$g_{H_S} = \delta_S(1 + \eta_S) + \frac{\alpha\eta_S\delta_S}{W_S} \left\{ \theta g_{H_F} - \delta_F\eta^\psi (W_S - W_M) + \rho - \psi(\theta-1)[\delta_S(1 + \eta_S) - \delta_M(1 - \eta_M)] \right\} \quad (20)$$

$$g_{H_M} = \delta_M(1 - \eta_M) - \frac{(1-\alpha)\eta_M\delta_M}{W_M} \left\{ \theta g_{H_F} - \delta_F\eta^\psi (W_S - W_M) + \rho - \psi(\theta-1)[\delta_S(1 + \eta_S) - \delta_M(1 - \eta_M)] \right\} \\ \left/ \left[\psi(\theta-1) \left(\frac{\alpha\eta_S\delta_S}{W_S} - \frac{\beta\eta_M\delta_M}{W_M} \right) \right] \right. \quad (21)$$

Proposition 3 shows that in the case of human capital migration, human capital accumulation will be affected by two aspects.

First of all, the efficiency of human capital accumulation will be affected by human capital migration.

In the case of the forward-flow of human capital, the human capital accumulation rate in services needs to increase by $(1 + h_S)$ times based on the sectoral human capital accumulation efficiency parameter δ_S . This implies that the accumulation of human capital in services will change from H_S as the base of human capital when there is no human capital migration to $\bar{H}_S$ as the base of human capital when there is human capital migration.

Therefore, human capital migration increases the stock of human capital and the accumulation rate of human capital in services.

Accordingly, the human capital accumulation rate in manufacturing needs to decrease by $(1-h_M)$ times based on the sectoral human capital accumulation efficiency parameter d_M , indicating that the outflow of human capital reduces the manufacturing human capital to $\bar{H}_M$.

In the case of the reverse-flow of human capital, the decrease of human capital immigration into services leads to the decrease of h_S and h_M , the decrease of $(1+h_S)$ leads to the slow accumulation of human capital in services, and the increase of $(1-h_M)$ leads to the increase of the human capital accumulation in manufacturing. The accumulation of human capital itself is the main factor driving the change in the sectoral human capital stock, and cross-sector forward-flow and reverse-flow of human capital involves an adjustment of the sectoral human capital accumulation in the presence of cross-sector economic differences. Secondly, the migration of human capital will also affect the sectoral human capital accumulation difference, and then affect the accumulation of human capital.

Note that the sectoral human capital accumulation difference is as follows:

$$g_{H_S} - g_{H_M} = \frac{qg_{H_F} - d_F h^y (W_S - W_M) + r}{y(q-1)} \quad (22)$$

Thus the human-capital accumulation rates of the two sectors can be rewritten as:

$$g_{H_S} = d_S(1+h_S) + \frac{a h_S d_S (g_{H_S} - g_{H_M}) - [d_S(1+h_S) - d_M(1-h_M)]}{W_S} \quad (23)$$

$$g_{H_M} = d_M(1-h_M) - \frac{b h_M d_M (g_{H_S} - g_{H_M}) + [d_S(1+h_S) - d_M(1-h_M)]}{W_M} \quad (24)$$

Eq. (22) shows that the higher the forward migration rate of human capital is, the greater the difference of human capital accumulation rate between services and manufacturing is, whereas the reverse migration of human capital will reduce the difference of sectoral human capital accumulation rate. Eq. (23) shows that the rate of human capital accumulation in services is positively related to the sectoral

human capital accumulation difference. The forward migration of human capital will promote the accumulation of human capital in the services by expanding the sectoral human capital accumulation difference, on the contrary, the reverse migration of human capital will hinder the accumulation of human capital in the services by reducing the sectoral human capital accumulation difference. Eq. (24) shows that the rate of human capital accumulation in manufacturing is negatively related to the sectoral human capital accumulation difference. Therefore, the forward migration of human capital will hinder the accumulation of human capital in manufacturing by expanding the sectoral human capital accumulation difference. On the contrary, the reverse migration of human capital will promote the accumulation of human capital in manufacturing by reducing the sectoral human capital accumulation difference. In addition, Eqs. (23) and (24) also show that the sectoral human capital accumulation rate is negatively related to term $[d_S(1+h_S) - d_M(1-h_M)]$. This term is the difference in the efficiency of sectoral human capital accumulation with the influence of human capital migration. The efficiency of human capital accumulation caused by human capital migration cannot change too much. The forward flow of human capital will lead to the increase of term $d_S(1+h_S)$ and the decrease of term $d_M(1-h_M)$, and the increase of term $[d_S(1+h_S) - d_M(1-h_M)]$ will have a negative impact on sectoral human capital accumulation. The continuous forward flow of human capital will increase this negative effect, and thus gradually produce the requirements for reverse flow of human capital. When the reverse flow of human capital, the decrease of term $[d_S(1+h_S) - d_M(1-h_M)]$ will have a positive impact on sectoral human capital accumulation.

5.2 Sectoral and Aggregate Growth

By solving the Hamiltonian in Eq. (16), the sectoral and aggregate economic growth rates in equilibrium can be obtained, as shown in the following proposition.

Proposition 4: In the human capital reverse-flow model, when manufacturing and services both lie on their respective SBGPs, the two sectors attain equilibrium growth along their SBGPs, and the aggregate economy achieves a

unique ABGP equilibrium. The equilibrium growth rates for the two sectors are given by:

$$g_{Y_S} = d_S - d_F h^Y (W_S - W_M) + \left(1 + \frac{y h_S d_S}{d_F h^Y W_S}\right) g_{H_F} \quad (25)$$

$$g_{Y_M} = d_M - d_F h^Y (W_S - W_M) - \left(\frac{y h_M d_M}{d_F h^Y W_M} - 1\right) g_{H_F} \quad (26)$$

The ABGP growth rate of the aggregate economy is as follows:

$$g_Y = \frac{1}{q-1} [d_F h^Y (W_S - W_M) - g_{H_F} - r] \quad (27)$$

From Eq. (22), the sectoral economic growth rates can be rewritten as:

$$g_{Y_S} = d_S + \frac{y h_S d_S}{d_F h^Y W_S} g_{H_F} - \frac{r}{q} \quad (28)$$

$$+ \frac{q-1}{q} [y(g_{H_S} - g_{H_M}) - d_F h^Y (W_S - W_M)]$$

$$g_{Y_M} = d_M - \frac{y h_M d_M}{d_F h^Y W_M} g_{H_F} - \frac{r}{q} \quad (29)$$

$$+ \frac{q-1}{q} [y(g_{H_S} - g_{H_M}) - d_F h^Y (W_S - W_M)]$$

According to Eq. (28), when human capital flows forward from manufacturing to services, services will get more human capital investment, which will promote the growth rate of services. In addition, the sectoral human capital accumulation difference is also enlarged, and it also promotes the economic growth of services. Then the economic growth rate of services will be greatly improved. Whereas, when human capital flows reversely, services will get less migrant human capital, and g_{H_F} and $(g_{H_S} - g_{H_M})$ will decrease, then the economic growth rate of services will be hindered.

According to Eq. (29), when human capital flows forward from manufacturing to services, manufacturing will suffer a large amount of human capital outflow, the increase of g_{H_F} will lead to the decrease of g_{Y_M} . Whereas, the sectoral human capital accumulation difference is $(g_{H_S} - g_{H_M})$ also enlarged, which will partially offset the negative impact of g_{H_F} on g_{Y_M} , so the economic growth of manufacturing will be more gentle. On the other hand, when human capital flows backward, the outflow of human capital of manufacturing will decrease, the decrease of g_{H_F} will lead to the increase of g_{Y_M} . Whereas, $(g_{H_S} - g_{H_M})$ decreases and becomes negative, and has a negative effect on g_{Y_M} , which will partially offset the positive

impact of g_{H_F} on g_{Y_M} .

It can be seen that the forward- and reverse-flow of human capital have an impact on the sectoral economic growth through two channels: the migration of human capital and the difference in the sectoral accumulation of human capital. It has a greater stimulating effect on the economic growth of the services, but a more moderate effect on the economic growth of the manufacturing. This also explains that in the process of structural change, the output share of services changes faster, while that of manufacturing changes more slowly.

Notice that Eq. (27) can be rewritten as:

$$g_Y = g_{H_F} - y(g_{H_S} - g_{H_M}) \quad (30)$$

The reverse-flow of human capital will change the sign and the absolute value of g_{H_F} and $(g_{H_S} - g_{H_M})$, so the impact of the reverse-flow of human capital on the aggregate economic growth should be comprehensively evaluated. If the influence of g_{H_F} on g_Y is greater than that of $y(g_{H_S} - g_{H_M})$ when the human capital flows forward, and the influence of $y(g_{H_S} - g_{H_M})$ on g_Y is greater than that of g_{H_F} when the human capital flows backward, both the forward and reverse flows of human capital have positive effects on the aggregate economic growth.

5.3 De- and Re-Industrialization

With the continuous development of economy, social wealth and consumption level are increasing, which greatly stimulates the development of services. The services has gradually developed into a leading sector in the economy. In the process of the development of services, a lot of human capital investment is needed, which leads to the migration of human capital from manufacturing to services. Services has gained more and more human capital. The immigration of human capital promotes the production of services, and the growth rate of services increases.

As the manufacturing is highly productive and greatly affected by technological progress, the development of manufacturing is relatively gentle when there is no major breakthrough in technological progress. In the process of industrial structure upgrading, manufacturing gradually loses its dominant position, which leads to the gradual outflow of human capital from manufacturing industry. The growth momentum of manufacturing is not as strong as

that of services, and brain drain reduces the growth rate of manufacturing.

The increase of the growth rate of services leads to the strong rise of services, and the output share of services gradually accelerates to rise. The decrease of the growth rate of manufacturing leads to the relatively gentle decline of the output share of manufacturing, and deindustrialization occurs.

With the continuous development of services and the further improvement of consumption level, the high demand for service products gradually leads to higher consumption and investment risks, and the high risk of services also increases its wage level. The manufacturing is mostly engaged in real economic activities, with less virtual economic activities. The risk of manufacturing is relatively low, and the wage level is relatively flat. As a result, the relative wage of services to manufacturing gradually rises and exceeds its threshold value, which leads to the reverse-flow of human capital.

The reverse-flow of human capital reduces the high growth rate of services, restrains the excessive growth of services, prevents the further spread of the high risk of services, and plays a positive role in stabilizing the sectoral and the aggregate economic growth. The reverse-flow of human capital strengthens the growth of manufacturing, arouses people's attention to the real economy and technological progress, and plays a positive role in reducing economic risks. The growth of services is still strong, but the growth slows down, and the output share of services increases at a decreasing rate. The growth rate of manufacturing has gradually increased from a relatively low value to a relatively high value, which leads to the decelerating decline or even gentle increase of the output share of manufacturing, and the trend of reindustrialization has emerged.

Deindustrialization and reindustrialization are both natural processes. The fundamental reason is that human capital is subject to the threshold value of sectoral wage gap and appears to flow forward and reversely. The trend of deindustrialization is due to the forward-flow of human capital from manufacturing to services, while the trend of reindustrialization is due to the reverse-flow of human capital from services to manufacturing. The flow direction of human capital between industries leads to the change

of industrial growth rate and the change of the trend of industrial output share in the process of industrial structure upgrading. The forward-flow and reverse-flow of human capital is the root cause of industrial upgrading and the trend of deindustrialization and reindustrialization. In the process of deindustrialization, the output share of manufacturing shows a gentle decline, while in the process of reindustrialization, it shows a decelerating decline (that is, the decline rate is lower than that in the period of deindustrialization), and finally it rises smoothly. Whereas the output share of services shows an accelerating increasing trend in the process of deindustrialization, but increasing at a decreasing rate in the process of reindustrialization. This is a new form of economic structure change under the condition of human capital reverse-flow.

6. Conclusions

This paper characterizes the dynamic process of human capital migration, with particular emphasis on the equilibrium conditions under which human capital exhibits reverse-flow behavior. Building on this foundation, it analyzes how both forward-flow and reverse-flow of human capital influence human capital accumulation, sectoral economic growth, and aggregate economic growth. Furthermore, it examines the decisive role of bidirectional human capital flows in shaping the trends of deindustrialization and reindustrialization, and distills the novel features of economic structural change under a migration regime characterized by reverse-flow mechanisms.

This paper argues that the bidirectional cross-sector flow of human capital—both forward and in reverse—is the key mechanism driving either the continuation or the reversal of structural change. The conditions for flow reversal hinge on the sign of the product of two terms related to sectoral wages. When this product is negative, human capital flows forward: the manufacturing output share declines, the services output share accelerates, and the economy enters a stage of deindustrialization. Conversely, when the product is positive, human capital flows in reverse: the manufacturing output share rises, the services output share decelerates, and the economy enters a stage of reindustrialization.

In the early stages of deindustrialization, the government should expedite the development of migration-supporting institutions, refine

migration mechanisms, and facilitate the forward flow of human capital, thereby accelerating the shift in the locus of economic growth from manufacturing to services. In the later stages, as the inter-sectoral wage gap narrows and approaches the critical threshold, the government should curb excessive expansion of the service sector to mitigate economic risks and forestall excessive deindustrialization; simultaneously, it should remove barriers to the return of human capital, improve return mechanisms, and facilitate a smooth reverse flow of human capital, thereby enabling a seamless transition from deindustrialization to reindustrialization. Finally, our model can be extended in several directions, such as incorporating more complex determinants of human capital migration and accounting for human capital externalities.

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