Sectoral Structural Change in a Knowledge Economy

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Abstract

The sectoral composition of the US economy has changed dramatically in the past six decades. At the same time, knowledge and information assets are becoming increasingly important in the value creation process of a modern economy. This paper aims to explain the recent sectoral structural change from the perspective of differences in intangible capital accumulation across sectors. In the two-sector model of the paper, as the importance of intangible capital increases in the production functions – but at different rates across sectors – labor is shifted from direct goods production to creating sector-specific intangible capital. At the mean time, the real output and employment shares of the high intangible sector increase.

The implications of the model are consistent with the following stylized facts in US economy: (1) the high intangible sector has expanded in both output and employment; (2) intangible capital investment increases in both sectors; (3) the economy's employment composition is shifting towards occupations engaging in intangible investment activities; (4) both sectors' labor productivity growth has declined over time, especially for the high intangible sector.

I further test the relationship between intangible capital and structural change at more disaggregate levels. The industry-level results suggest that an industry's future growth in output and employment is strongly correlated with its intangible capital intensity. The firm-level results show that the industries in which firms' intangible investments have a higher impact on firm production tend to grow more. Both results are consistent with the theory of the paper.

The industry level data also indicates that the expanding service industries are primarily intangible capital intensive. Thus the theory developed in this paper also helps to explain the rise of the service sector in recent decades.

*I am tremendously grateful to my advisor Jinhui Bai for his guidance and encouragement. I would also like to thank Behzad Diba and Mark Huggett for helpful comments and discussions. My appreciation also goes to Sami Alpanda, Nadia Doytch, Luca Flabbi, Geng Li, Josh Rusenko, Leo Sveikauskas, and Francis Vella. All errors are, of course, my own.

1 Introduction

It is a well-known fact that less than half of the economic growth today can be explained by the "tangible" inputs, namely, physical capital and labor. Traditionally, macroeconomists attribute other factors involved in economic value creation to a "residual" term in the production function, which largely remains outside the scope of macroeconomic research. More recently, researchers have started recognizing that besides plants, equipment, land and labor, there are other systemic production inputs that are equally, if not more important in a modern knowledge economy, such as intangible capital. This paper studies the role of intangible capital in the recent sectoral structural change in the US.

The relative importance of various sectors in US economy has been going through dramatic change over time. For example, in the past five decades, the growth of most service-producing industries have largely outpaced that of goods-producing industries. What factors caused the structural change is an intriguing question. Different answers to the question have different implications for long-term economic growth and employment performance.

This paper develops a supply-side explanation of structural change based on sectoral differences in intangible capital accumulation. The basic idea is that the share of intangible capital in the production function differs across sectors. When the productivity of intangible investment increases with exogenous technology progress, more intangible capitals can be produced, given the amount of resources committed. Because intangible capital has a larger contribution to the production process in some sectors than in others, the intangible-capital intensive sector's output increases disproportionately with the productivity increase in intangible investment. At the same time, to take advantage of the increased investment productivity, firms shift labor from direct goods production to intangible capital creation, and this shift is to a larger scale in the intangible capital intensive sector. Take the total employment of a sector as the sum total of the sector's direct production labor and its intangible investment labor. The employment share of intangible-capital intensive sector would increase due to the disproportional expansion of its intangible investment labor.

The term intangible capital refers to knowledge and information based assets, including knowledge acquired through R&D and other creative activities, knowledge embedded in computer software and databases, firm-specific human and structural resources like management experience and brand names.

Modern firms engage in a wide range of knowledge-building activities, such as designing new products, processes and business models, training employees, marketing brands, developing computerized assets, communicating within and without the organization and acquiring information about markets and competitors. These activities mostly do not create any physical assets. However, they create knowledge-based resources indispensable in generating new values for customers and financial returns for the firm. The nature of these business activities is not very different from investment in physical capital – both generate productive resources for the future. In this sense, they should be viewed as capital investment when we analyze the firm's production process.

The advancement in information and communication technology has greatly enhanced the productivity of intangible capital investment in the past several decades. The most obvious change the IT revolution brought about is the proliferation of software and computerized information systems as new forms of intangible assets. But more importantly, it increases the effectiveness of many other knowledge investment endeavors. For example, progress in communication technology and new media increased the reach of firms' marketing efforts. The emergence of internet made many new business models possible, especially in the service sector. Computer networks make finding and sharing of information within and between business entities easier and faster. The use of computer software facilitated innovative work that produces knowledge assets. For instance, an architect who spent days crafting a blue print with pencil and paper can now create the same design in a few hours on a computer. Moreover, the proliferation of information provides powerful tools for managers and directors of enterprises. It promotes such organizational investment as flexible firm structure and decentralized decision-making processes.[1] The result of increased investment productivity is a surge of intangible capital investment in the economy over the recent decades. The empirical evidence of this trend will be reviewed in the next section.

The present paper is motivated by a set of new stylized facts about the linkage between the rise of intangible capital and sectoral structural change during the same period. In the past several decades, the high-intangible-capital industries have grown faster than their low intangible peers. In Figure 1, US SIC two-digit industries are divided into two sectors according to industry intangible capital investment intensity.[2] Figure 1 plots the real output and employment size of the high intangible capital sector as a proportion of the total private industries. Notice that in a span of five decades, the intangible capital intensive sector has experienced much more rapid growth in both real output and employment than the other sector.

Not only has the high-intangible capital sector expanded, intangible capital investment itself has also increased over time. Figure 2 shows intangible capital investment trends for the high and low intangible sector respectively. A sector's intangible investment intensity is calculated as the median investment intensity across industries within the sector. It is easy to see that both growing and declining sectors' intangible capital investments are increasing over time. However, the growing sector's intangible investment increases faster than that of the declining sector.

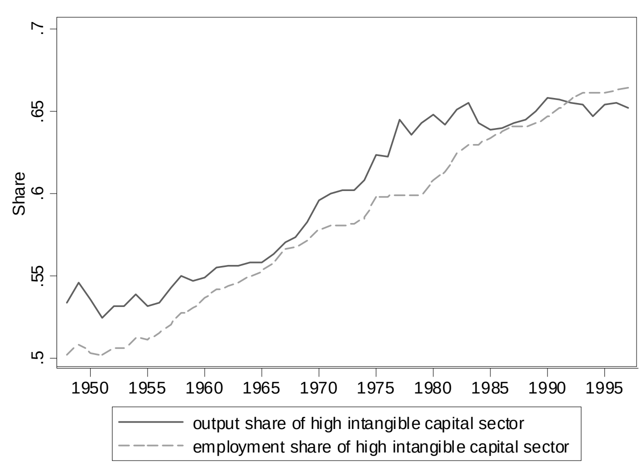

Figure 1: Shares of the intangible capital intensive sector

[1] See Brynjolfsson & Saunders (2009) for a detailed discussion about the relationship between information technology and organizational capital investment.

[2] The methodology of sector classification will be discussed in the calibration Section 4.1.

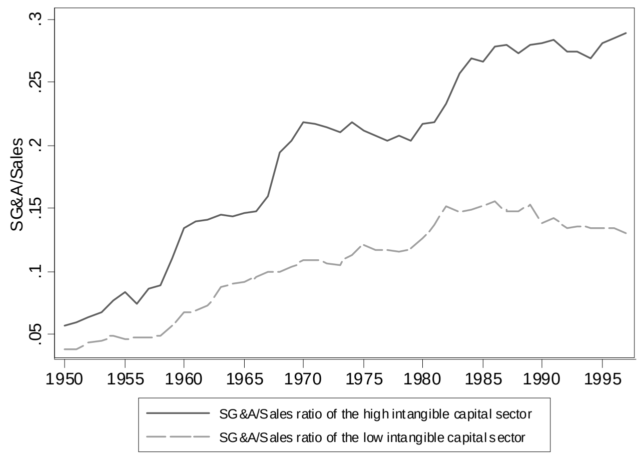

Figure 2: Intangible capital investment trends

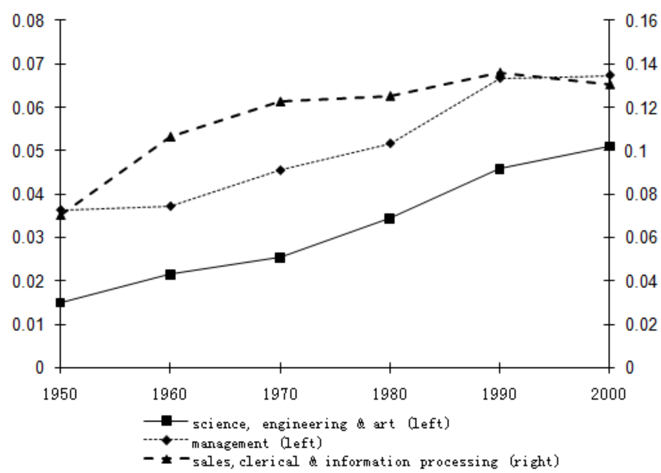

Figure 3: Rise of employment engaging in intangible capital investment

In conjunction with the structural change in sectoral composition, the employment composition of the economy has also been shifting – from direct goods production to intangible capital investment activities. In Figure 3, I selected several groups of occupations in which work activities typically involve intangible capital production, and calculated their shares in total employment.[3] These occupations are divided into three categories: 1) jobs that mainly involve creativity and innovation, such as engineers, architects, scientists, artists, and entertainers; 2) jobs that deal in organization construction and maintenance, such as managers, administrators, HR specialists, and business consultants; 3) jobs that fulfill marketing and communication functions, such as advertising personnel, customer service representatives, and IT operators. Figure 3 indicates that the share of workers engaging in intangible investment as a proportion of the total working population

[3]Data source: Steven Ruggles, Matthew Sobek, Trent Alexander, Catherine A. Fitch, Ronald Goeken, Patricia Kelly Hall, Miriam King, & Chad Ronnander. Integrated Public Use Microdata Series: Version 4.0. Minneapolis, MN: Minnesota Population Center [producer and distributor], 2009.

have been increasing overtime.[4]

The fourth stylized fact is concerning the productivity growth of the two sectors. Table 1 shows the annual average labor productivity growth[5] of the high and low intangible sectors in two sub-periods of the industry data sample and for the whole sample period from 1950 to 1997.[6] Two things are worth noticing. First, the labor productivity growth has declined in both sectors overtime. Second, the decline is more significant in the growing, high intangible sector. Thus for the whole sample period, the high intangible sector has on average lower productivity growth than the other sector, though its productivity growth is higher in the first sub-period.[7]

Annual Labor Productivity Growth (%)			
	1951-1973	1974-1997	1951-1997
High Intangible Sector	2.92	-0.94	0.95
Low Intangible Sector	2.16	0.72	1.43

Table 1: Labor productivity growth of the two sectors

The model of the paper replicates most of the stylized facts presented above. In terms of sectoral composition, the calibrated model generates significant increase in the high intangible sector's output and employment shares, the magnitudes comparable to the data. The model also produces rising intangible investments in both sectors, and increasing share of intangible investment labor in the total employment. Finally, both sectors' labor productivity growths decline overtime in the model simulation, and the decline is greater in the high intangible sector.

The empirical part of the paper tests the relationship between intangible capital accumulation and structural change with industry and firm data. The industry-level regressions show that intangible capital intensity has a strong positive correlation with future industry growth in output and employment. The result is robust to the inclusion of other industry characteristics that might impact industry growth. At the firm level, I also find that an industry tend to expand more when intangible investment has a higher impact on the growth of firms in the industry, i.e., when intangible capital is more important in the industry's production function. These findings are consistent with the paper's theory.

The rest of the paper is organized as follows. Section 2 gives a review of related literature. Section 3 presents a two-sector model featuring intangible capital accumulation, and discusses how

[4] One thing to keep in mind is that this is a very rough measure of the intangible-investment workforce, in the sense that (1) the occupation groups are selected subjectively according to common observations; they are by no means exclusive; (2) for many occupations, included in the list or not, working hours may be split between direct production and intangible investment activities. Therefore, Figure 2 should be taken as suggestive evidence, instead of a precise measure of intangible investment labor.

[5] Here the sectoral labor productivity is calculated as a sector's total real value-added devided by total labor hours.

[6] The BEA stopped producing industry output and employment data by SIC industry classification in 1997 and shifted to NAICS classification. To ensure consistency, I use SIC industry data for the most part of the paper. Therefore the sample period ends at 1997.

[7] This fact is related to the famous "cost disease" hypothesis by William Baumol (Baumol, 1967). The hypothesis was originally focused on the expansion of service industries. It assumes that service industries are intrinsically less likely to experience productivity improvement than goods-producing industries. A direct implication is that as the less productive industries grow bigger, it will eventually bring down the growth of the whole economy. This paper will show later that most of the expanding service industries are high intangible industries. Thus the result in Table 1 seems to be consistent with Baumol's hypothesis. However, as will be discussed in the calibration section, the conventional way to calculate labor productivity does not take into account the fact that part of the labor force is not directly engaged in the production of goods and services, but instead producing intangible investment goods which are not counted in the final outputs. And this is especially true for the high intangible sector.

the model can generate sectoral structural change. Section 4 calibrates the model and presents simulation results. Section 5 undertakes empirical analyses to test the implication of the model. Section 6 applies the paper's theory to explain the rise of service sector in recent decades. Section 7 concludes.

2 Related Literature

Although the neoclassical view of economic growth places little emphasis on sectoral composition change, some early literature from distinguished authors pointed out that structural change is in fact an integral part of growth. Baumol (1967) divided the economy into "progressive" and "non-progressive" sectors according to their rate of productivity growth. He proposed that over time, resources would shift to the sector with lower productivity and that sector would eventually determine the growth rate of the whole economy. Kuznets (1973) suggested two causes of sectoral composition change: shifting income elasticity of demand for different sectors and uneven rates of technological progress.

Recent literature are more or less expositions of the above rationales. For example, Echevarria (1997), Laitner (2000) and Kongsamut, Rebelo & Xie (2001) motivate structural change by assuming non-homothetic preferences in the utility function. Acemoglu & Guerrieri (2008) provides a two-sector model with different physical capital intensities in the sectoral production functions. They show that with aggregate capital deepening in the economy, the real output share of the sector that relies more on capital increases, but at the same time, resources are shifted towards the sector with low capital intensity because of low elasticity of substitution between different sectoral goods. A similar assumption is adopted by Ngai & Pissarides (2007). In their model, structural change is interpreted as labor shifting to sectors with low technological progress, whose shares of employment and nominal output increase over time.

However, as pointed out by Buera & Kaboski (2007), the rise of many advanced service industries since the mid-20th century is an expansion of not only nominal output shares, but also real output shares of those industries. The story of low elasticity of substitution between sectoral goods runs counter to the latter observation. Moreover, theories that assume non-homothetic preferences of consumers neglect the fact that many rising industries, such as business and financial services, are in fact not final goods providers, and their rise can hardly be explained as a result of differences in income elasticity.

In contrast, the present paper made simple and standard assumptions about households' utility function and do not rely on demand elasticity to generate the structural change results. The present paper identified the cross-sectoral difference in intangible capital intensity as an important source of structural change. The shift in employment shares of sectors is motivated by the change in work tasks from direct goods production to intangible capital production, unlike in most of the existing supply-side literature, which mainly relies on low elasticity of substitution between sectors to generate realistic structural change in employment.

A crucial difference between the industrial-age economy and the modern knowledge economy is that cutting-edge production know-how is no longer embodied in plants, properties and equipment, but are increasingly intangible, carried with workers and organizations. Moreover, the advancement of IT technology drastically reduced the cost of information processing, facilitated applied innovations and transformed the characteristics of business communication. The emergence of IT, as a general purpose technology, both requires and enables new investments in such intangible assets as organizational structure and management processes.

There is abundant evidence suggesting that the business sector's intangible capital investments have been on the rise over the past six decades. Companies' market value as a percentage of GDP has been increasing since the 1980s', while tangible assets relative to GDP declined during the same period. Some researchers argue that an important source for the increase in firms' market capitalization is the accelerated accumulation of intangible assets (e.g., Hall, 2001). Nakumura (2001) inferred the amount of business intangible investment in US economy, using data on industrial expenditures, labor inputs and corporate operating margins. He concluded that by 2000, private firms invested at least $1 trillion annually in intangible assets, and 1/3 of US corporate assets are in intangibles. Corrado, Hulten & Sichiel (2005, 2006) directly estimated and aggregated different components of business intangible capitals. They concluded that by the end of the 20th century, intangible capital investment had exceeded private firms' physical capital investment, amounting to about 13% of business outputs. Atkeson & Kehoe (2005) emulated plant-life dynamics based on organization capital accumulation. They estimated that the payments to intangible capital owners are on average 110% of those to physical capital owners. According to the above estimations, it is a reasonable conjecture that given the large increase of intangible investment in the economy, it can have impact, and large impact, on the characteristics of production and employment in different sectors.

There is a diverse and quickly expanding literature that relates intangible capital investment to various macroeconomic phenomena.[8] The present paper, to my best knowledge, is the first one to analyze the relationship between intangible capital accumulation and the sectoral structural change in modern economy.

3 Theory

3.1 Model

The model economy is inhabited by a representative household with the preference[9]

$$\sum_{t=0}^{\infty} \beta^t \ln(C_t)$$

The economy has two sectors, which produce their respective sectoral goods $Y_1$and Y_2. A final good is produced competitively by combining the two sectoral goods:

$$Y_t = Y_{1t}^{\gamma_1} Y_{2t}^{\gamma_2} \tag{1}$$

[8] Prescott & Visscher (1980) modeled the information accumulation and transfer process within a firm (a type of organization capital investment), and used it to explain stylized characteristics of firm growth rates and size distributions. Hall (2001) argued that US firms' intangible asset accumulation helps explain the persistent high valuation of common stocks compared to companies' book values. Atkeson & Kehoe (2005) linked the amount of organization capital a plant accumulated with the size of plant-specific rents. They simulated plant distribution dynamics driven by organization capital accumulation, and showed that the result fit the real data well. Jovanovic & Rousseau (2001) hypothesized that the quality of organization capital differs across generations of firms, which explained the "cohort effects" in firms' stock market performance. Brynjolfsson, Hitt & Yang (2002) found that investment in intangible assets complements investment in IT technology, and the combined investment has a significantly larger impact on firms' output and market valuation than isolated investments. McGrattan & Prescott (2007) introduced business intangible investment in a standard growth model and demonstrated that it helped explain US productivity and investment boom in the 1990s. Danthine & Jin (2007) modeled different stochastic processes in intangible capital accumulation and argued that it contributed to high volatility in equity returns.

[9] Here the utility function is in log form and welfare is only derived from consumption. These specific assumptions serve to simplify the non-essential part of the model. A more complicated utility function won't change the major results of the model.

where $\gamma_1 + \gamma_2 = 1$.[10]

I assume that there is only one firm in each sector, and the sectoral goods production function is Cobb-Douglas:

$$Y_{i,t} = K_{i,t}^{a_{i,t}} O_{i,t}^{b_{i,t}} L_{y_i,t}^{1-a_{i,t}-b_{i,t}}, \qquad i = 1, 2$$

where K_i, O_i, L_{y_i} are respectively physical capital, intangible capital and labor engaged in producing sectoral goods Y_i. An important feature of the model is that the factor shares in the production functions, a_{it} and b_{it}, can exogenously change over time, due to changes in technology and production methods.

Physical capital and labor are freely mobile across sectors. The physical capital is assumed to accumulate according to the log-linear form

$$K_{t+1} = K_t^{1-\delta} I_t^{\delta} \tag{2}$$

where $(1-\delta)$ captures the impact of current capital stock on the amount of capital available next period. The log-linear assumption of physical capital formation, combined with log consumer utility, allows us to obtain a closed form solution to the static equilibrium of the model.

Intangible capital is sector-specific and not directly transferrable between the two sectors. It accumulates according to

$$O_{i,t+1} = (1-\varphi) O_{i,t} + X_{i,t}, \qquad i = 1, 2 \tag{3}$$

where $X_{i,t}$ is the intangible investment good in sector i. The production of X_i requires intangible capital and labor inputs:

$$X_{i,t} = B_{i,t} O_{i,t}^{1-d} L_{o_i,t}^{d}$$

L_{o_i} is the part of labor engaged in producing intangible capital. Note that unlike physical capital and labor, the intangible capital O_i is not split between sectoral goods production and intangible investment. The intuition is that the same knowledge, brand name and experiences can be used both to create consumable values and to develop new knowledge, brands and experiences. $B_{i,t}$denotes the productivity level of sector i's intangible capital investment at period t, which is exogenously given and grows at an annual rate g_{B_i}: $B_{i,t} = B_{i,t-1}(1 + g_{B_i})$.

The final output Y can be used either for consumption or for physical capital investment: $C_t + I_t \leq Y_t$. In other words, the physical capital investment good is of the same unit as consumption. Let q_i denote the price for IC investment goods X_i, and let $\widetilde{Y}$ denote the extended aggregate output: $\widetilde{Y}_t = Y_t + q_{1t}X_{1t} + q_{2t}X_{2t}$. Then the economy's resource constraint can be expressed as

$$C_t + I_t + q_{1t}X_{1t} + q_{2t}X_{2t} \leq \widetilde{Y}_t \tag{4}$$

Labor supply in the economy is inelastic and equal to the population size at time t, $\overline{L}_t$. Capital and labor market clearing requires that

$$\begin{aligned} &K_{1,t} + K_{2,t} \leq K_t \\ &L_{y_1,t} + L_{y_2,t} + L_{o_1,t} + L_{o_2,t} \leq \overline{L}_t \end{aligned} \tag{5}$$

[10] Equation 1 implies that the elasticity of substitution between the two sectoral goods is equal to 1. This means that the ratio between the nominal values of the two sectoral goods is always constant – any relative quantity changes are exactly off-set by corresponding changes in prices. The purpose of this assumption is to differentiate the employment structural change mechanism described in the present paper from the mechanism used in some other supply-side structural change papers that rely on non-unity elasticity of substitution between sectors to create labor composition change (e.g., Acemoglu & Guerrieri (2008); Ngai & Pissarides (2007)).

3.2 Competitive Equilibrium

The competitive equilibrium of the model has the following features. First, consumers save by purchasing physical and intangible capitals; they then rent capital services to firms in the next period and sell the un-depreciated capitals. Second, the sectoral goods are used to form consumption and physical capital investment, while intangible capital investment goods are produced separately, with $1/q_i$ representing the relative marginal cost of X_i in terms of consumption and physical investment. Third, the household chooses consumption and physical capital investment, and also the level of intangible investment by choosing the labor inputs going into producing intangible investment goods.

The state of the economy at the beginning of time t is described by $\xi_t = (a_{1t}, a_{2t}, b_{1t}, b_{2t}, B_{1t}, B_{2t}, O_{1t}, O_{2t}, K_t, \overline{L}_t)$. Assume that the equilibrium wage and rental rates are expressed as functions of ξ_t: $w_t = W(\xi_t)$; $r_t^k = R^k(\xi_t)$; $r_t^{o_1} = R^{o_1}(\xi_t)$; $r_t^{o_2} = R^{o_2}(\xi_t)$. Capital stocks evolve according to functions $K_{t+1} = K(\xi_t)$, $O_{1,t+1} = O_1(\xi_t)$, $O_{2,t+1} = O_2(\xi_t)$. The optimization problems of the household and firms are the following.

The household's optimization problem is

$$\max_{\{C_t, I_t, L_{o_1,t}, L_{o_2,t}\}_{t=0}^{\infty}} E \sum_{t=0}^{\infty} \beta^t \ln(C_t) \tag{P1}$$

subject to the constraints

$$\begin{gathered} C_t + I_t + q_{1t}X_{1t} + q_{2t}X_{2t} \le w_t L_t + r_t^k K_t + r_t^{o_1} O_{1t} + r_t^{o_2} O_{2t}; \\ X_{i,t} = B_{i,t} O_{i,t}^{1-d} L_{o_i,t}{}^{d} \\ O_{i,t+1} = (1-\varphi) O_{i,t} + X_{i,t}, \qquad i = 1, 2 \\ K_{t+1} = K_t^{1-\delta} I_t^{\delta} \end{gathered}$$

The firms' maximization problem is

$$\max_{\widetilde{L}_{y_i,t}, K_{it}, \widetilde{O}_{it}} \pi_{it} = p_{it} Y_{it} - w_t \widetilde{L}_{y_i,t} - r_t^k K_{it} - r_t^{o_i} \widetilde{O}_{it}; \qquad i = 1, 2 \tag{P2}$$

Because of the constant return to scale and competitive market assumption, the firms make zero profits each period in the equilibrium.

A competitive equilibrium is a set of decision rules $C = C(\xi)$, $I = I(\xi)$, $L_{y_1} = L_{y_1}(\xi)$, $L_{y_2} = L_{y_2}(\xi)$, $L_{o_1} = L_{o_1}(\xi)$, $L_{o_2} = L_{o_2}(\xi)$, $K_1 = K_1(\xi)$, $K_2 = K_2(\xi)$, a set of prices $w = W(\xi)$, $r^k = R^k(\xi)$, $r^{o_1} = R^{o_1}(\xi)$, $r^{o_2} = R^{o_2}(\xi)$, and aggregate laws of motion for capital stocks $K_{t+1} = K(\xi_t)$, $O_{1,t+1} = O_1(\xi_t)$, $O_{2,t+1} = O_2(\xi_t)$, such that

1. Household solves problem (P1), taking as given ξ, and pricing functions $W(\cdot)$, $R^k(\cdot)$, $R^{o_1}(\cdot)$, $R^{o_2}(\cdot)$. The solution to the household's problem satisfies $C = C(\xi)$, $I = I(\xi)$, $L_{o_1} = L_{o_1}(\xi)$, and $L_{o_2} = L_{o_2}(\xi)$.

2. Firms solve problem (P2), given ξ and functions $W(\cdot)$, $R^k(\cdot)$, $R^{o_1}(\cdot)$, $R^{o_2}(\cdot)$. The solution to the firm's problem satisfies $\widetilde{L}_{yi} = L_{y_i}(\xi)$, $\widetilde{O}_i = O_i$, and $K_i = K_i(\xi)$; $i = 1, 2$.

3. The aggregate resource constraint 4 holds in every period. Labor and capital markets clear:

$$K_{1t} + K_{2t} \leq K_t$$
$$L_{y_1,t} + L_{y_2,t} + L_{o_1,t} + L_{o_2,t} \leq \overline{L}_t$$

Normalize the price of the final good to 1. Then the equilibrium prices of the two sectoral goods can be denoted as

$$p_{1t} = \gamma_1 \frac{Y_t}{Y_{1t}}, \quad p_{2t} = \gamma_2 \frac{Y_t}{Y_{2t}} \tag{6}$$

From the solution to firms' maximization problem, the wage rate should be equal to the marginal productivity of labor, which can be expressed relative to the final good price as

$$w_t = (1 - a_i - b_i)\, \gamma_i \frac{Y_t}{L_{y_i,t}}$$

Therefore the ratio of direct production labor between the two sectors is constant and can be written as

$$\frac{L_{y_1,t}}{L_{y_2,t}} = \frac{\gamma_1(1 - a_1 - b_1)}{\gamma_2(1 - a_2 - b_2)} \tag{7}$$

Similarly, equalizing the marginal productivity of physical capital between the two sectors, we have

$$\frac{K_{1,t}}{K_{2,t}} = \frac{\gamma_1 a_1}{\gamma_2 a_2} \tag{8}$$

Since in the equilibrium the marginal productivity of labor between sectoral goods production and IC investment is equal, we can derive the prices for IC investment goods, $q_{i,t}$, as

$$q_{it} = \frac{(1 - a_i - b_i)\, r_i Y_t L_{o_i,t}}{d X_{i,t} L_{y_i,t}}; \qquad i = 1, 2 \tag{9}$$

As I assume that the markets are complete in this economy, the model can also be solved as a social planner's problem. The Lagrangian for the social planner's problem is

$$\begin{aligned}
\mathcal{L} \;=\; & \sum_{t=0}^{\infty} \beta^t \{\ln(C_t) + \lambda_t [Y_{1t}^{\gamma_1} Y_{2t}^{\gamma_2} - C_t - \frac{K_{t+1}^{1/\delta}}{K_t^{(1-\delta)/\delta}}] + \sum_{i=1,2} \mu_{it} [K_{i,t}^{a_i} O_{i,t}^{b_i} L_{y_i,t}^{1-a_i-b_i} - Y_{i,t}] \\
& + \sum_{i=1,2} \eta_{it} [(1-\varphi)\, O_{i,t} + B_{i,t} O_{i,t}^{1-d} L_{o_i,t}^{d} - O_{i,t+1}] + \theta_t (L_t - L_{y_1,t} - L_{y_2,t} - L_{o_1,t} - L_{o_2,t}) \\
& + \phi_t (K_t - K_{1,t} - K_{2,t})
\end{aligned}$$

From the first order conditions of the planner's problem,[11] it can be shown that the household always consumes a fixed proportion S_c of the final goods produced each period:

$$S_c = 1 - \frac{\beta\delta(\gamma_1 a_1 + \gamma_2 a_2)}{1 - \beta(1-\delta)}$$

[11] Specified in the appendix.

3.3 Comparative Statics

In this section I show that structural change in static equilibrium can be produced either (1) by altering the intangible investment-specific productivity growth, g_{B_i}, or (2) by changing the sectoral production structures, i.e., changing a_i and b_i in the sectoral goods production functions.

First, note that the Euler equation for intangible capital accumulation in each sector can be written as

$$\frac{(1-a_{it}-b_{it})L_{o_i,t}^{1-d}}{dB_{it}O_{i,t}^{1-d}L_{y_i,t}} = \frac{\beta(1-\varphi)(1-a_{i,t+1}-b_{i,t+1})L_{o_i,t+1}^{1-d}}{dB_{i,t+1}O_{i,t+1}^{1-d}L_{y_i,t+1}} + \frac{\beta(1-d)(1-a_{i,t+1}-b_{i,t+1})L_{o_i,t+1}}{dO_{i,t+1}L_{y_i,t+1}} + \frac{\beta b_{i,t+1}}{O_{i,t+1}} \tag{10}$$

In the steady state, $O_i = \frac{B_i L_{o_i}^d}{(g_{B_i}+\varphi)^{1/d}}$. Equation 10 can thus be written as

$$\frac{(1-a_i-b_i)}{d\left(g_{B_i}+\varphi\right)L_{y_i}} = \frac{\beta(1-\varphi)\left(1-a_i-b_i\right)}{d(1+g_{B_i})\left(g_{B_i}+\varphi\right)L_{y_i}} + \frac{\beta(1-d)\left(1-a_i-b_i\right)}{d(1+g_{B_i})L_{y_i}} + \frac{\beta b_i}{(1+g_{B_i})L_{o_i}}$$

from which we can calculate the labor allocation within sector i:

$$\frac{L_{o_i}}{L_{y_i}} = \frac{\beta b_i d\left(g_{B_i}+\varphi\right)}{\left(1-a_i-b_i\right)\left[(1+g_{B_i})(1-\beta)+\beta d(g_{B_i}+\varphi)\right]} \tag{11}$$

Then it is easy to determine the factors that can affect the within-sector labor allocation:

Proposition 1 *In the static equilibrium,*

$$\frac{\partial\left(L_{o_i}/L_{y_i}\right)}{\partial b_i} > 0, \frac{\partial\left(L_{o_i}/L_{y_i}\right)}{\partial g_{B_i}} > 0, and \frac{\partial^2\left(L_{o_i}/L_{y_i}\right)}{\partial g_{B_i}\partial b_i} > 0.$$

In other words, increases in b_i and g_{B_i} can both lead to a shift in labor allocation from direct goods production to intangible capital investment. And the effects of the two parameters can reinforce each other.

Proof. Taking derivative of Equation 11 with respect to b_i and g_{B_i}. ■

Sector i's intangible investment cost at time t is $q_{it}X_{it}$. The steady state intangible investment intensity is also a function of b_i and g_{B_i}:

Proposition 2 *The steady-state intangible investment cost to output ratio in sector i can be written as*

$$\frac{q_i X_i}{p_i Y_i} = \frac{\beta b_i\left(g_{B_i}+\varphi\right)}{(1+g_{B_i})(1-\beta)+\beta d(g_{B_i}+\varphi)}, \tag{12}$$

which is an increasing function of b_i and g_{B_i}.

Proof. *Equation 12 can be derived from combining Equation 9, 6, and Equation 11. Then simply take derivative of Equation 12 with respect to b_i and g_{B_i}.* ■

According to Proposition 1 and 2, the considerable increase in intangible investment/output ratios since the 1950s, and the shift of employment towards knowledge work suggest that either the importance of intangible capital has increased in the production functions (increasing b_i), or the intangible investments have become more efficient(increasing g_{B_i}), or both, if we assume that d and φ are relatively constant over time. Section 4 will explore these possibilities through calibration and simulation.

Notice that the employment of sector i is the sum of direct production labor and intangible investment labor:

$$L_i = L_{y_i} + L_{o_i}.$$

The following proposition describes how the economy's sectoral composition of employment changes with the importance of intangible capital in the production functions and with the productivity of intangible investment:

Proposition 3 *In the steady state,*

$$\frac{\partial(L_1/L_2)}{\partial g_{B_1}} > 0, \ \frac{\partial(L_1/L_2)}{\partial g_{B_2}} < 0; \tag{13}$$

When $g_{B_1} = g_{B_2} = g_B$,

1.

$$\frac{\partial(L_1/L_2)}{\partial g_B} > 0, \ \textit{if} \ \frac{b_1}{b_2} > \frac{1-a_1}{1-a_2}. \tag{14}$$

and

$$\frac{\partial(L_1/L_2)}{\partial b_1} > 0, \text{ if } \frac{\partial a_1}{\partial b_1} < \frac{-(1-\beta)(1+g_B)}{(1-\beta)(1+g_B)+\beta d(g_B+\varphi)}; \tag{15}$$

Proof. The proof for Proposition 3 is included in the appendix. ■

Equation 15 says that sector 1's employment share will increase as intangible capital becomes more important in sector 1's production function, provided that intangible capital is at least to some extent physical capital substituting. Equation 13 and 14 state that sector 1's employment share will increase when sector 1's efficiency of intangible investment improves faster relative to the other sector. And when intangible investment productivity grows at the same rate for the whole economy, sector 1's employment share is likely to increase with the intangible productivity growth if sector 1 is more capital intensive in either type or both types of capital than the other sector.

The propositions in this section give directions for generating structural changes in the model economy. Before we calibrate the changes in parameters and simulate the model, it is helpful to look at the long-run feature of the economy when the production structure is constant, as will be described in the next section.

3.4 Balanced Growth (when production structures do not change)

To examine the long-run growth path of the economy, let's assume for now that the factor shares in the production functions are constant. The economy in the long run can thus be characterized as a balanced growth path, where consumption, physical capital and final output grow at a constant rate, while the output shares of the two sectors can keep shifting.

First, the intangible investment productivities B_i grow at the exogenous rates g_{B_i}. From the resource constraint (4) and physical capital accumulation rule (2) it is easy to see that Y, C, I, K have to grow at the same rate. Let's denote the rate as g_y. On the other hand, from intangible capital accumulation equation (3) it follows that O_i grows at rate g_{o_i}, which satisfies

$$(1+g_{o_i}) = (1+g_{B_i})^d$$

The final goods production function (1) implies that

$$(1+g_y) = (1+g_y)^{a_1\gamma_1+a_2\gamma_2}(1+g_{o_1})^{b_1\gamma_1}(1+g_{o_2})^{b_2\gamma_2}$$

Therefore, on the balanced growth path the growth rate of the final output is determined by the intangible investment productivity growth of both sectors:

$$1+g_y = (1+g_{B_1})^{\frac{db_1\gamma_1}{1-a_1\gamma_1-a_2\gamma_2}}(1+g_{B_2})^{\frac{db_2\gamma_2}{1-a_1\gamma_1-a_2\gamma_2}}$$

Let the ratio between the two sectoral outputs be $\phi_t = \frac{Y_{1t}}{Y_{2t}}$. If the two sectors share the same intangible investment productivity growth rate: $g_{B_1} = g_{B_2} = g_B$, then the growth rate of ϕ, g_ϕ, can be expressed as

$$1+g_\phi = \frac{\phi_{t+1}}{\phi_t} = (1+g_B)^{\frac{db_1(1-a_2)-db_2(1-a_1)}{1-a_1\gamma_1-a_2\gamma_2}} \tag{16}$$

Therefore, the long-run output composition of the economy is determined by g_B and different factors' shares in the two sectors' production functions:

Proposition 4 *Let $g_B > 0$. Sector 1's real output share $\frac{\phi_t}{1+\phi_t}$ approaches 1 asymptotically: $lim_{t\to\infty}\frac{\phi_t}{1+\phi_t} = 1$, if $\frac{b_1}{b_2} > \frac{1-a_1}{1-a_2}$.*
Proof. *$\frac{b_1}{b_2} > \frac{1-a_1}{1-a_2}$ implies that g_ϕ is positive. The rest of result is straightforward.* ■

In other words, the sector that is more intensive in either type of capital, or in both, is going to be the expanding sector in terms of its real output share, provided that g_B is positive. However, the amount of labor allocated to each production activity always remains constant on the balanced growth path. Therefore, there will be no employment composition change in this economy without changes in production parameters. The goal of the next section is thus to investigate whether the model can generate more realistic structural change through calibrated production structure changes.

4 Calibration and Simulation

In this section I assign parameter values to the model, simulate the model, and compare the results to the empirical data in sectoral composition change, trend of intangible investments, occupational composition change and trend in sectoral labor productivity growth. The section proceeds in the following steps: (1) describing in details the method of sector categorization in the data; (2) discussing the calibration strategy and parameter choices; (3) presenting baseline simulation results; (4) presenting sensitivity check results.

4.1 Sector Categorization

First, the two sectors, as presented in figure 1, are constructed as follows. The industry output and employment data is from BEA and intangible investment data from COMPUSTAT North America. I divide SIC two-digit industries into two sectors, that of high and low intangible-capital intensities. Following the recent empirical accounting literature,[12] I use firms' "sales, general & administrative expenditure" (SG&A) as an approximation of firms' intangible capital investment. Intangible capital intensity is measured by SG&A expenditure to sales ratio for a firm, and by

[12] See Section 5.2.

the within-industry median SG&A/sales ratio, for an industry. Industries are then ranked and assigned into two sectors according to the their average intangible-capital intensity from 1950 to 1997.[13] The publicly-traded firms contribute to, on average, over 50% of total business sector output.

Table 2a-b list the sector categorization for SIC two-digit industries and their intangible capital intensities. One thing to notice is that service industries concentrate more in the high intangible capital sector. The theory of this paper can thus help to explain the expansion of service industries over goods-producing industries in recent decades. Section 6 will discuss service sector's rise in more details.

Industry	**Sector**	**intangible capital intensity**
Coal mining	Low	0.063
Primary metal	Low	0.080
Textile mill products	Low	0.101
Petroleum refining	Low	0.102
Water transportation	Low	0.104
Nonmetallic minerals	Low	0.105
Motor freight transportation and warehousing	Low	0.105
Construction	Low	0.110
Paper and allied products	Low	0.114
Transportation equipment	Low	0.115
Railroad transportation	Low	0.121
Metal Mining	Low	0.123
Stone, clay, glass and concrete products	Low	0.128
Transportation services	Low	0.135
Electric, gas and sanitary services	Low	0.139
Lumber and wood products	Low	0.140
Insurance carriers	Low	0.141
Agriculture	Low	0.146
Wholesale trade	Low	0.147
Air transportation	Low	0.149
Fabricated metal	Low	0.159
Rubber and plastics	Low	0.161
Oil and gas extraction	Low	0.167
Amusement and recreation services	Low	0.169
Hotels and lodging places	Low	0.172
Holding and other investment offices	Low	0.175

Table 2a: Sector categorization by intangible capital intensity (1950-1997): low intangible sector

[13] Note that since firms' financial data are taken from COMPUSTAT, it only includes publicly-traded companies and may bias towards large firms. If large firms tend to invest more in intangible assets than their smaller peers, it can inflate the measure of intangible capital intensity. However, since this bias exist in both sectors, and it is mainly the relative scale of intangible intensity between sectors that affect the simulation results, for the purpose of our simulation exercise, the impact of this bias should be negligible.

Industry	Sector	intangible capital intensity
Automotive repair and services	High	0.176
Furniture and fixtures	High	0.179
Apparel and fabrics	High	0.186
Food products	High	0.192
Electronics	High	0.203
Health services	High	0.206
Motion pictures	High	0.207
Leather and leather products	High	0.209
Machinery and computer equipment	High	0.214
Retail trade	High	0.224
Miscellaneous manufacturing	High	0.226
Communications	High	0.230
Real estate	High	0.234
Engineering, accounting, research & management	High	0.238
Tobacco products	High	0.239
Personal services	High	0.241
Non-depository institutions	High	0.246
Local and suburban transit	High	0.250
Depository institutions	High	0.253
Security and commodity brokers	High	0.261
Measuring, analyzing and controlling instruments	High	0.275
Printing, publishing and allied industries	High	0.281
Chemicals and allied products	High	0.284
Business Services	High	0.284
Insurance agents, brokers and service	High	0.306
Miscellaneous repairs	High	0.315
Educational services	High	0.417

Table 2b: Sector categorization by intangible capital intensity (1950-1997): high intangible sector

4.2 Calibration Strategy and Parameters

According to Proposition 3, sector i's employment share increases when b_i is higher, i.e., when intangible capital becomes more important in the sectoral production function. As the model simulation will show, sector $\acute{i}$'s output level will also shift with changes in b_i. Thus by tracking the changes in b_i for the two sectors over time, we can produce sectoral composition changes in the model.[14]

To calibrate b_i, intangible capital's share in the sectoral production functions, recall from Equation 12 that in the steady state,

$$b_i = \frac{q_i X_i}{p_i Y_i} \frac{(1+g_{B_i})(1-\beta)+\beta d(g+\varphi)}{\beta\,(g_{B_i}+\varphi)} \tag{17}$$

where $\frac{q_i X_i}{p_i Y_i}$ is the intangible investment to output ratio of sector i; the rest of the RHS variables are predetermined parameters. With Equation 17, we can infer the values and changes of b_1 and

[14] Proposition 3 also states that the employment composition of the economy would change with the productivity growth rate of intangible investment, g_B. Thus I also experimented calibration with changing g_B. However, the simulation results show that the magnitude of structural change generated through that approach is too small to match the real data. Thus it seems that the impact of changing intangible investment efficiency on sectoral composition is a minor one. The results are not reported here and are available upon request.

b_2 for each year from the time series of $\frac{q_i X_i}{p_i Y_i}$, using the sectors' SG&A/Sales ratios as the intangible investment to output ratios. Note that since Equation 17 describes a steady state relationship, the time-series of b_i calculated in this way are only approximation of the "true" values. Fortunately, since the changes in $\frac{q_i X_i}{p_i Y_i}$ are incremental each year, the calibrated b_is turn out reasonably close to the real values – as the simulation result will show, the gaps between the real intangible investment to output ratios and the simulated series are quite small.

Table 3 presents the summary statistics of the calibrated b_i.

	Mean	Std . Dev.	Min	Max
$b_{1,t}$	0.189	0.074	0.057	0.285
$b_{2,t}$	0.103	0.037	0.038	0.153

Table 3: Summary Statistics for calibrated b

The values of physical capital's shares in the sectoral production functions, a_1 and a_2, are set to evolve according to the following rule:

$$a_{i,t} = a_{i,t_0} - \tau_i \left(b_{i,t} - b_{i,t_0} \right); \qquad t_0 \leq t \leq T$$

where τ_1 and τ_2 are set at 1 and 0.5 respectively in the baseline simulation. The initial year t_0 corresponds to Year 1950 in real data, when COMPUSTAT data was first available. The initial values of a_1 and a_2, and the two sectors' shares in the final goods production function, γ_1 and γ_2, are chosen so that the output and employment shares of the two sectors are of similar scales to those in the data. This leads to $\gamma_1 = 0.65$, $\gamma_2 = 0.35$, $a_{1,t_0} = 0.6 - b_{1,t_0}$, and $a_{2,t_0} = 0.45 - b_{2,t_0}$.

The labor supply is fixed at unity throughout the simulaiton. The growth rate of intangible investment productivity g_B is set at zero, to diffrentiate the impact of production structure change on sectoral composition from the impact of intangible investment productivity change. The rest of the parameters that need to be decided are the following: $\{\beta, d, \delta, \varphi\}$. Physical capital's depreciation rate is set at the standard value $\delta = 0.08$. The depreciation rate of intangible capital is harder to estimate and may differ across categories of intangibles. Following related literature,[15] I choose $\varphi = 0.5$. d, labor's share in the intangible capital investment function, is set at 0.9 for both sectors in the baseline simulation. The following table provides a summary of the chosen parameter values:

β	γ_1	γ_2	δ	φ	d	$\overline{L}$	g_B	τ_1	τ_2
0.96	0.65	0.35	0.08	0.5	0.9	1	0	1	0.5

4.3 Simulation of the Model

The following assumptions are made in computing the model: (1) the economy is at an original steady state before period t_0, with factor shares in the production functions constant and equal to those at t_0; (2) the economy is at a new steady state after period T, with factor shares constant and equal to those at time T; (3) at t_0, the agents have complete information about the current values and future changes of factor shares in the production functions. The time paths of all variables are solved by computing the numerical solution to the system of first order conditions from t_0 to T. t_0 and T are set to be the beginning and ending year of the data sample: 1950 and 1997 respectively.

[15] For example, Corrado et al (2006) uses the following depreciation schedules: 33% for computerized information, 20% for R&D, 60% for brand equity, 40% for firms' structural resources.

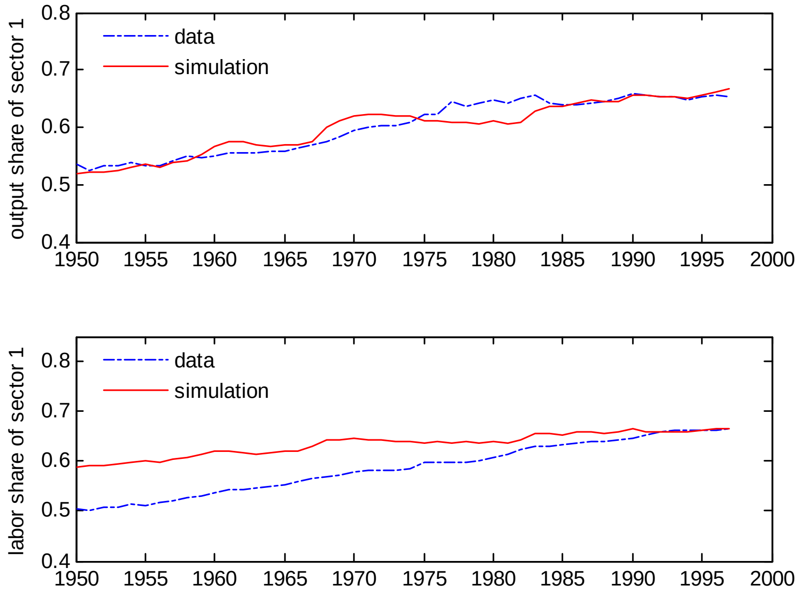

Figure 4: Sectoral composition change

Figure 4 reports the simulation results for the output and employment shares of sector 1, which is assumed to be the intangible capital intensive sector, in the 48 year time span. For comparison, the empirical data is plotted in the same graphs. Again, the shares of sector 1 in both output and employment have increased significantly during the period. In the model, sector 1's output share increased 28%, from 0.52 to 0.67, compared to 22% in the data, from 0.54 to 0.65. On the employment side, the share of sector 1 rose 13%, from 0.59 in the beginning period to 0.67 in the ending period, compared to 32% in the data, from 0.5 to 0.66.

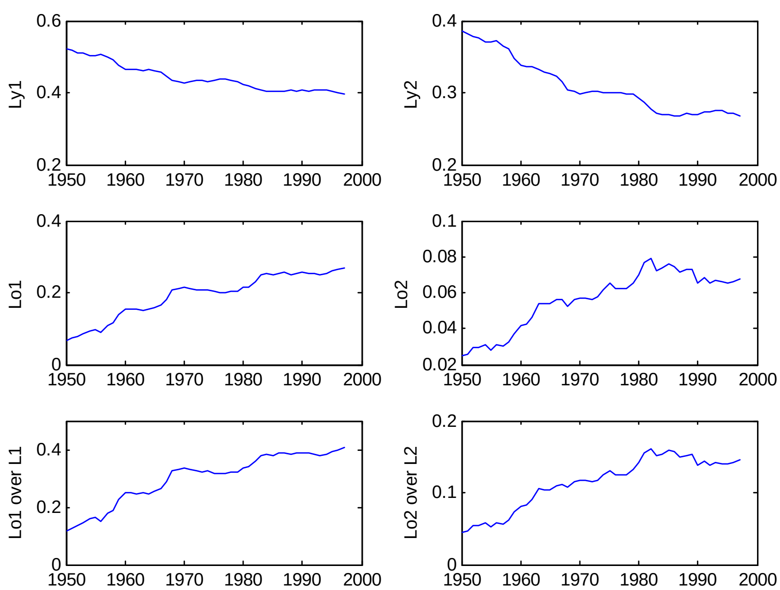

Figure 5: Within-sector labor allocation

Since the ratio of workers engaged in direct goods production between the two sectors – L_{y_1}/L_{y_2} – is constant, the increase in sector 1's share of employment is primarily driven by the fact that more labor is allocated to intangible investment activities. Figure 5 presents the trend of labor allocation between direct goods production and intangible capital investment in the two sectors. Over time in both sectors labor is shifted from producing sectoral goods to producing intangible capital. But this shift is of a larger magnitude in sector 1, where intangible capital is always more important in the production function. Sector 1's employment share increases as a result.

This mechanism of structural change through shifting work activities is one innovation of the paper compared to earlier structural change literature. It is also consistent with the stylized fact of changing occupational composition of the economy towards intangible investment related work, as described in the introduction section. Table 4 reports the share of total labor allocated to intangible investment in the model, calculated as $(L_{o_1} + L_{o_2})/\overline{L}$, for year 1950, 1970 and 1997. As a comparison, the total employment shares of the three intangible investment related occupation groups in the US, as presented in Figure 2[16], are also listed Again, the shares of these professions give a suggestive estimate for the trend of intangible investment labor's share in the total labor force. The message of Table 4 is that as in the data, the model produces increasing share of intangible investment labor. But the magnitude of increase is higher than the data.

	Labor engaged in intangible investment activities as a proportion of total employment (%)		
	1950	1970	1997
Data	12.18	19.37	24.90
Model	9.25	27.29	33.64

Table 4: Shares of intangible investment labor

Next I look at the labor productivity growth in the two sectors. The first row of Table 5 lists the average annual growth rate of labor productivity for the two sectors – calculated as sectoral real output divided by total hours worked – in the data from 1951 to 1997. As mentioned in Section 1, the key characteristics of the data are the following. First, for the earlier sub-period (1951-1973), the high-intangible sector has a higher labor productivity growth than the low-intangible sector, while the opposite is true for the second sub-period (1974-1997). On average, the productivity growth of the high intangible sector is lower than the other sector. Second, both sectors' productivity growth is lower in the second sub-period than in the first, and this drop is more significant in the high intangible sector than in the low intangible sector.

These facts are mostly captured in the model. The second row of Table 5 reports the simulated productivity growth of the two sectors. Matching the productivity measure in the data, here labor productivity in sector i is calculated as sectoral output over total employment in the sector, $Y_i/\left(L_{y_i} + L_{o_i}\right)$. As in the data, the high intangible sector has higher productivity growth than the other sector in the first sub-period. Both sectors' productivity growth declined in the second sub-period. And the decline is greater in the high intangible sector than in the low intangible sector. But in contrast to the data, due to the fact that the decrease of high intangible sector's productivity growth is less dramatic in the model, when the entire sample period is counted, the high intangible sector's productivity growth is still higher than the other sector.

Another thing to note is that in the present model's framework, the ratio $Y_i/\left(L_{y_i} + L_{o_i}\right)$, which is the counterpart of "labor productivity" in the data, is in fact not the "true" labor productivity

[16] Again, the three occupational groups are: science, engineering and artistical professionals, management professionals, and sales, clerical and information processing professionals. The number for Year 1997 is extrapolated from the data in 1990 and 2000.

in sectoral goods production. Because the sectoral employment includes L_{o_i}, which is not used in producing Y_i. And the true labor productivity in producing sectoral goods should be Y_i/L_{y_i}. The third row of Table 5 calculated the growth rate of the labor productivity calculated this way. For both sectors, the true labor productivity growth is higher than those calculated in the standard way. However, due to the limited information we can get from the currently available employment data, it is not yet possible to seperate L_{o_i} from L_{y_i} and calculate the true labor productivity in the real economy.

		Annual labor productivity growth (%)					
		High intangible sector			Low intangible sector		
		1951-1973	1974-1997	1951-1997	1951-1973	1974-1997	1951-1997
Data:	$Y_i / (L_{yi} + L_{oi})$	2.92	-0.94	0.95	2.16	0.72	1.43
Model:	$Y_i / (L_{yi} + L_{oi})$	2.47	1.67	2.06	1.65	1.26	1.45
Model:	Y_i / L_{yi}	3.63	2.21	2.91	2.14	1.47	1.80

Table 5: Labor productivity growth of the two sectors

Figure 6 reports the simulated intangible investment to output ratios in the two sectors, and compared them to the SG&A/Sales ratios in the data. Not surprisingly, the simulated intangible investment intensity rises in both sectors. And the gaps between the simulated series and the real data are fairly small: 0.0013 per period for sector 1 and 0.0006 per period for sector 2.

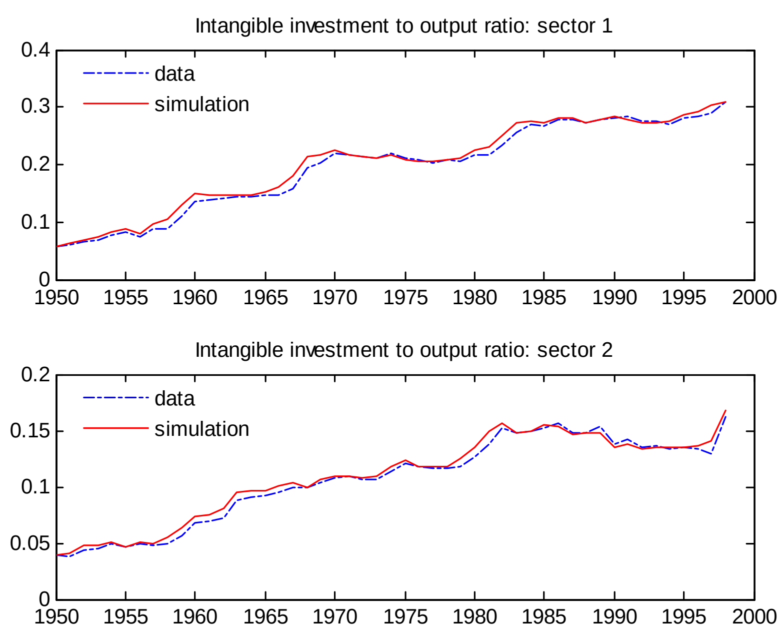

Figure 6: Intangible investment to output ratios

Overall, the calibration results show that the model is capable of reproducing the following stylized facts in the data: (1) increasing real output and employment shares of the high intangible sector; (2) shifts in employment composition towards intangible investment activities; (3) increasing intangible capital investment intensities in both sectors; (4) decreasing labor productivity growth in both sectors, and a larger decrease in the high intangible sector. In terms of the magnitude of sectoral composition change, the simulated output share increase of the high intangible sector is slightly higher than that in the data, and the magnitude of employment share increase is about 50% of the data.

4.4 Sensitivity Analysis

Certain parameters in the baseline calibration were chosen fairly subjectively due to lack of information in the real data regarding their values. In this section I conduct sensitivity analyses to check how variations in these parameters might influence the simulation results. The parameters I focus on are: (1) the depreciation rate of intangible capital, φ, (2) the share of labor in intangible investment goods production function, d, and (3) the extend to which intangible capital substitutes for physical capital when its shares in the sectoral production functions increase, τ_i.

Table 6 reports the percentage growth of sector 1's real output and employment shares with alternative choices of parameters φ, d, and τ_2. Table 7 and 8 list the corresponding results of the changes in total intangible investment labor share and the two sectors' annual labor productivity growths respectively.

Let's look at the information in these tables parameter by parameter. Column 3 and 4 of Table 6 and Table 7 report structural change results when $\varphi = 0.25$ and when $\varphi = 0.75$. The results indicates that when the depreciation rate of intangible capital is higher, the intangible intensive sector expands less in terms of both output and employment. Meanwhile the share of L_o in total employment is slightly lower when the depreciation rate is higher. The intuition of the results is the following: when the intangible capital depreciates slower, the future payoff of current period investment is higher. This encourages more intangible investment. Therefore, L_{o_i} is higher in both sectors, and more so in sector 1, where intangibles are more important. And the larger increase in L_{o_1} drives up the employment share of sector 1 much like before, but to a greater extent. Slower depreciation also increases the stocks of O_i, and raises the relative output of sector 1 higher as intangible capital has a higher share in sector 1's production function.

	Data	Baseline	$\varphi = 0.25$	$\varphi = 0.75$	d = 0.7	d = 0.4	$\tau_2 = 1$	$\tau_2 = 0.3$
Sector 1's output share change (%)	21.80	28.08	32.51	25.68	24.05	17.58	22.74	30.18
Sector 1's employment share change (%)	31.81	12.78	12.94	12.64	10.69	7.38	10.06	13.91

Table 6: Sector 1's share changes with alternative parameters

Column 5 and 6 of Table 6 and Table 7 report structural change results when $d = 0.7$ and when $d = 0.4$. When current period labor input is more important in intangible investment goods production (higher d), sector 1's output and employment shares both increase more, and the share of L_o in the total labor force is also higher. The result can be understood as follows. When the production of intangible investment goods is less dependent on current stock of O_i, and more dependent on current labor input level, the stock of O_i can increase faster corresponding to the increases in b_i. The potential to make more swift adjustment in investment is to the advantage of sector 1, as O_1 has a higher share in the sectoral production function. It also encourages labor to be shifted to L_{o_i} in both sectors.

	Labor engaged in intangible investment activities as a proportion of total employment (%)							
	Data	Baseline	$\varphi = 0.25$	$\varphi = 0.75$	d = 0.7	d = 0.4	$\tau_2 = 1$	$\tau_2 = 0.3$
1950	12.18	9.25	9.25	9.25	7.34	4.33	9.25	9.25
1997	24.90	33.64	34.50	33.06	28.44	19.05	32.85	33.97

Table 7: Share of labor engaged in intangible investment activities: alternative parameter values

Column 6 and 7 of Table 6 and 7 report results when $\tau_2 = 1$ and when $\tau_2 = 0.3$.[17] From the results we can see that the lower τ_2 is relative to τ_1, the larger is the expansion of sector 1. And the intangible investment labor's share in total labor force is also larger. The reason is that if intangible capital's share increases in sector 2's production function without eroding much the share of L_{y_2} (i.e., τ_2 is high), then the level of L_{y_2} will not decline much while the level of L_{o_2} increases, given the level of τ_1. Therefore on the whole, sector 2's labor share will be higher compared to the case when intangible capital substitutes for labor in sector 2's production function (low τ_2). On the other hand, when τ_2 is lower, more labor will be allocated to L_o, since L_{y_2} becomes less important in the production function as b_2 increases.

Overall, Table 6 and Table 7 shows that although parameter changes do bring about variations in the degree of structural change, the basic characteristics of the original simulation remain the same. Specifically, output and employment shares of sector 1 both rise over time, and the share of intangible investment labor increases. Generally, the change in output composition is more sensitive to parameter values than the employment composition. But no matter how the parameters change, compared to data, the model produces a higher increase in sector 1's output share, and a lower increase in its employment share

	Annual labor productivity growth (%)					
	High intangible sector			Low intangible sector		
	1951-1973	1974-1997	1951-1997	1951-1973	1974-1997	1951-1997
Data	2.92	-0.94	0.95	2.16	0.72	1.43
Baseline	2.47	1.67	2.06	1.65	1.26	1.45
$\varphi = 0.25$	3.25	2.13	2.68	2.07	1.58	1.82
$\varphi = 0.75$	2.08	1.46	1.76	1.44	1.11	1.27
d = 0.7	2.13	1.56	1.84	1.48	1.15	1.31
d = 0.4	1.73	1.42	1.57	1.31	1.04	1.17
$\tau_2 = 1$	2.60	1.72	2.15	2.01	1.30	1.65
$\tau_2 = 0.3$	2.42	1.66	2.03	1.51	1.25	1.37

Table 8: Productivity growth with alternative parameters

Table 8 reports the changes in labor productivity growth for both sectors with alternative parameter values. The message in Table 8 is, again, that the simulation results are fairly stable with respect to parameter changes. The 3rd and 4th rows of Table 8 report productivity growth results with variations in φ. When intangible capital depreciates slower, both sectors' labor productivity growths are higher. The 5th and 6th rows display productivity growth results with changes in d.

[17] The simulation results not reported here show that it is fundamentally the difference between τ_1 and τ_2 that impacts the magnitude of sectoral composition change. So for the sake of simplicity, I keep τ_1 unchanged (equal to 1).

When intangible investment relies more on current period input, thus more adjustable, both sectors have higher productivity growth. Finally, the 7th and 8th rows show that when τ_i is higher, that is, when intangible capital substitutes for physical capital instead of labor in the sectoral production function, both sectors' productivity growths are higher. In general, the characteristics of the baseline simulation remain present when parameter values change. Specifically, the productivity growth in the second sub-period is lower than in the first sub-period for both sectors, and sector 1's productivity growth declines more than that of sector 2.

5 Empirical Analysis

5.1 Overview

A central message from the theoretical section of the paper is that there is a close linkage between intangible capital intensity and sectoral output/employment growth in US economy for the past half century. Figure 1 already demonstrated this trend in data at a broad, two-sector level. In this section, using industry and firm data, I check whether the implication of the model also holds at more disaggregate levels. The purpose is twofold: first is to examine the universality of the model's prediction; and second is to provide a more micro level foundation for the secotral composition change depicted in Figure 1.

The section consists of two empirical exercises. The first one looks at industry-level data, and asks whether there is a positive linkage between industries' intangible capital intensity and their output and employment growth. Thus the exercise can partly be seen as a disaggregate counterpart of Figure 1. An important difference is that here I control for other industry characterisitcs that can potentially affect the structural change process, so as to differentiate the intangible capital effect on growth from other factors.

The second exercise examines the relationship between intangible capital intensity and growth at firm level, and asks whether firms' intangible investment intensity affects firm growth, and whether such an effect translates into growth differentials across industries. Together, these two exercises provide comprehensive tests of the paper's thesis and offer a more detailed view about the relationship between the rise of intangible capital and the structural change of sectoral/industrial composition in the economy.

5.2 Data

The current accounting rules only allow companies to directly recognize a small part of the actual intangible capital as "assets" on their balance sheets. Most of the investments in intangible capital are expensed in firms' Sales, General & Administrative expenditure (SG&A), which includes R&D cost, marketing expenses, management fees, software expenditures, etc. Therefore, recent empirical accounting literature have used SG&A expenditure as approximation for firms' intangible investment (e.g., Lev & Radhakrishnan (2005), Banker, Huang & Natarajan (2006), Eisfeldt & Papanikolaou (2009)). The present paper follows this practice. However, since SG&A is not a precise measure of firms' intangible investment, the related regression estimates should be seen as suggestive to the signs and magnitudes of the "true" coefficients. Four data sources are used in the empirical regressions: (1) COMPUSTAT North America, which contains publicly-traded firms' financial statement information, including SG&A expenditure, number of employees, annual sales, total assets, physical capital investment, etc.; (2) BEA annual industry accounts data with information of industries' value-added, price, and employment by SIC two-digit classification; (3)

BLS data of capital income and IT investment by industry; and (4) Education level of industry labor force from Current Population Survey. I select data with consistent industry classification from 1950 to 1997 at industry level, and from 1950 to 2007 at firm level. The summary statistics for the key variables at both levels are presented in Table 9.

	Mean	Std	Min	Max
	Firm level variables			
Sales ($mn)	1235.036	7073.271	0.009	375376
Employee (thousand)	8.500	32.890	0.001	2100
SG&A expenditure ($mn)	222.047	1196.523	0.002	70297
Physical capital investment ($mn)	85.020	603.041	0.001	40595.290
R&D expenditure ($mn)	53.643	341.054	0.000	12183
Total assets ($mn)	1722.129	24764.370	0.002	3771200
SG&A/sales	0.321	0.529	0.000	9.936
Physical capital investment/sales	0.098	0.309	0.000	9.838
Annual sales growth rate	0.098	0.367	-6.177	7.215
Annual employee growth rate	0.031	0.347	-6.321	7.255
	Industry level variables			
Annual real output share growth	-0.001	0.151	-2.387	2.158
Annual employment share growth	-0.006	0.052	-0.917	0.462
Real output share	0.018	0.026	0.0003	0.158
Employment share	0.018	0.028	0.0002	0.203
Industry SG&A/sales	0.181	0.096	0.000	0.694
Share of college-educated workers	0.345	0.187	0.014	0.878
IT investment/output	0.001	0.003	0.000	0.040
Capital income's share in value-added	0.397	0.193	0.004	0.963

Table 9: Summary statistics

5.3 Industry Level Estimation

5.3.1 Estimation Model

Applying the prediction of the theoretical model at the industry level, I test the following hypothesis: an industry's real output and employment growths are higher when it is more intangible capital intensive. The calibration section has shown that intangible capital's share in the production function is increasing with the intangible investment to output ratio. Thus our hypothesis can be tested by regressing industry output/employment share growth on industry's intangible investment to output level.

Specifically, I estimate the following equation:

$$\Delta \ln y_{j,t} = a_0 + a_1 INTAN_{j,t-s} + a_2 K_{j,t-s} + a_3 EDU_{j,t-s} + a_4 IT_{j,t-s} + a_5 \ln y_{j,t-s} + a_6 \Delta \ln y_{j,t-1} + \upsilon_{j,t} \quad (18)$$

where $\Delta \ln y_{j,t}$ can be either industry j's real output share growth or employment share growth from $t-s$ to t. $\ln y_{j,t-s}$ is the output share or employment share of industry j at $t-s$. $INTAN_j$ is industry j's intangible investment to output ratio, approximated by the median level SG&A expenditure/sales ratio of the industry. As before, $INTAN_{j,t}$ is increasing with intangible capital's share in industry j's production function at time t.

Various other industry characteristics may contribute to the growth differentials across industries. Therefore, I include other industry variables in Equation 18 as controls. These variables are chosen according to related literature on structural change and productivity growth, as outlined in the literature review section. They include: K_j, physical capital intensity of industry j, measured by capital income's share in industry value added; EDU_j, human capital intensity of industry j, calculated as the number of workers who received at least some college education as percentage of the total industry workforce; IT_j: the intensity of information technology investment in industry j, calculated as the ratio of industry IT investment to industry value-added.

As some of the above industry characteristics are not stationary over time[18], and we are mostly interested in the impact of the cross-industry differences in these explanatory variables, the standard scores of the above variables are used as regressors in the actual estimations.[19] Besides, given the fact that structural change is a slow process and changes in industry characteristics might not immediately translate into changes in industry growth, I set the baseline time lag s as 5 years. As a robustness check, I also estimated the model with $s = 3$ and $s = 10$.

The error term of Equation 18, $v_{j,t}$, contains an industry fixed effect and an observation specific error. Due to the fact that there is partial overlap between the dependent variables of adjacent time periods, a lagged dependent variable is included on the right hand side. This introduces correlation between the regressor and the error term. Therefore, I use the dynamic GMM estimator developed by Arellano & Bond (1991) in regressing the model. The estimator also eliminates endogeneity that may be caused by any correlation between the unobserved industry-specific factor and other right hand side variables.

5.3.2 Industry Level Regression Results

Table 10 presents the results of industry level regressions. Let's first look at the performance of the control variables for industry characteristics. The result for human capital intensity mostly confirms the prediction of Buera & Kaboski (2007): human capital has positive and significant impacts on industry's output and employment growth across all time windows. Similarly, the IT intensity variable is positively and significantly correlated with industry output share growth, which lends support to the argument advocating ICT as a general purpose technology and an important source of productivity growth. However, IT's impact on employment share growth is mixed, as the coefficient is positive and significant when $s = 3$, but turns negative and significant when $s = 5$ or 10. This result seems to indicate that ICT is likely be labor substituting in the medium and long run. For physical capital intensity, the coefficient is positive and significant in the output share growth regression except when $s = 3$, while the correlation between physical capital intensity and employment share growth is mostly negative. These results confirm the observation of Acemoglu & Guerrieri (2008), who found that since the 1950s, physical capital intensive industries' output shares have increased in the US and their employment shares decreased.

Now turn to the results for intangible capital. In the output share growth regression, the coefficients for lagged intangible capital intensity are all positive and significant except when $s = 10$, which is positive but not significant. In the employment share growth regressions, the coefficients for intangible capital intensity are all positive and significant. Quantitatively, the coefficients decrease as the time lag gets longer. And consistent with the simulation result, on average intangible capital intensity seems to have a larger impact on output share growth than on employment share growth.

Notice that all the diagnostics of the regression results are satisfactory. Specifically, the absence

[18] For example, industries' intangible capital, human capital and IT intensities have all been on the rise over the sample period.

[19] The standard score of variable z for industry i, $z_{it} = \frac{z_{it} - \overline{z}_t}{\sigma_{z_t}}$, where $\overline{z}_t$ is the mean of z at time t, and σ_{z_t} is the standard deviation of z.

of 1st order serial correlation is rejected and the absence of 2nd order serial correlation is not rejected. Also the Hansen test for overidentification restrictions is not rejected. These results indicate that the regression specification used here is an appropriate one.

Overall, the industry-level regression results suggest a strong positive correlation between intangible capital intensity and future industry growth. The impact of intangible capital on growth does not seem to be driven by other industry characteristics.

Table 10: Intangible capital intensity and industry growth[20]

	Output share growth			Employment share growth		
	3 year window	5 year window	10 year window	3 year window	5 year window	10 year window
Intangible capital intensity	0.152***	0.028***	0.001	0.062***	0.013***	0.003***
	(0.019)	(0.003)	(0.002)	(0.009)	(0.002)	(0.000)
Human capital intensity	0.242***	0.034***	0.015***	0.126***	0.042***	0.001*
	(0.017)	(0.007)	(0.003)	(0.010)	(0.006)	(0.000)
IT intensity	0.280***	0.046***	0.033***	0.033***	-0.011**	-0.003***
	(0.013)	(0.004)	(0.003)	(0.008)	(0.005)	(0.000)
Physical capital intensity	-0.025**	0.010***	0.004**	-0.010	-0.001	-0.001***
	(0.011)	(0.002)	(0.002)	(0.008)	(0.002)	(0.000)
Output / employment size	-0.826***	-0.172***	-0.079***	-0.409***	-0.090***	-0.015***
	(0.013)	(0.005)	(0.002)	(0.025)	(0.003)	(0.001)
N	1543	1439	1179	1543	1439	1179
AR 1 test (p-value)	-2.89	-3.03	-2.89	-2.47	-2.86	-3.04
	(0.004)	(0.002)	(0.004)	(0.013)	(0.004)	(0.002)
AR 2 test (p-value)	-0.88	-1.63	-0.07	0.1	-1.59	-0.34
	(0.381)	(0.102)	(0.944)	(0.924)	(0.113)	(0.734)
Hansen J test (p-value)	33.96	33.08	23.37	31.09	36.04	46.26
	(0.241)	(0.194)	(0.381)	(0.361)	(0.114)	(0.379)

5.4 Firm Level Estimation

5.4.1 Estimation Model

The purpose of this section is to examine whether intangible capital investment also has an impact on the output and employment growth at firm level; and if so, whether the degree of such impact is related to differences in industry growth, which then leads to the aggregate-level structural change.

In a real economy, each sector or industry normally consists of multiple firms. And even for firms in the same industry, capital investment levels vary due to factors such as cross-firm differences in productivity and demand prospect. Assume that firms in the same industry share basically the same production structure in terms of different inputs' importances in the production function. Then it can be proved in the model that the same unit of intangible investment would have a more

[20] ***: p<0.01; **: p<0.05; *: p<0.1.

positive impact on firm growth for firms in the industries where intangible capital is more important in the production function.[21] At the same time, according to our theory these industries are also expected be the expanding industries. Therefore we can test the linkage between intangible capital intensity and industrial structure change from a more disaggregate perspective. Specifically, the hypothesis to test is the following: firms' intangible investment has a positive impact on firms' output and employment growth; and the industries in which firms' intangible investment has a higher impact are the expanding industries.

To test this hypothesis, I estimate the following equation:

$$\begin{aligned} g_{ij,t} &= \beta_0 + \beta_1 \left(\frac{SG\&A}{Sales}\right)_{ij,t-1} + \beta_2 \left(\frac{SG\&A}{Sales}\right)_{ij,t-1} \times grow_j + \beta_3 \left(\frac{I_k}{Sales}\right)_{ij,t-1} \\ &+ \beta_4 \left(\frac{I_k}{Sales}\right)_{ij,t-1} \times grow_j + \beta_5 grow_j + \beta_6 \text{control}_{ij,t-1} + u_{ij,t} \end{aligned} \tag{19}$$

where the dependent variable $g_{ij,t}$ is either the sales growth rate or the employment growth rate of firm i in industry j from $t-1$ to t; $\frac{SG\&A}{Sales}$ is firm's SG&A expenditure scaled by firm sales, which measures a firm's intangible investment level; $grow_j$ is the output share growth of industry j from 1950 to 1997.[22] To make sure that the coefficient for SG&A is not a substitute for the impact of other investments, and also to compare the effect of intangible capital on growth with that of physical capital investment, I include $\frac{I_k}{Sales}$, firm's physical capital investment scaled by sales, and its interaction with $grow_j$ as regressors. Since it is likely that firm growth is influenced by firm age and size, I include these factors as control variables. The former is approximated by the number of years a firm is listed on the stock market[23], and the latter by firms' sales and total assets at $t-1$. Other factors such as business cycle fluctuation and industry-specific factors can also affect firm growth. Thus the error term of Equation 19 contains firm and time fixed effects: $u_{ij,t} = \mu_{ij} + \varepsilon_t + v_{ij,t}$, where $v_{ij,t}$ is assumed to be i.i.d. across firms with mean 0 and variance σ_v^2.

From Equation 19, the impact of intangible investment on firm growth is

$$\frac{\partial g_{ij,t}}{\partial (SG\&A/Sales)_{ij,t-1}} = \beta_1 + \beta_2 grow_j$$

Again, if intangible capital plays any role in industry j's production process, firms' intangible investments are expected to have a positive impact on firm growth; and the degree of this impact is determined by the importance of intangible capital in industry j's production function. If industry j's long-run growth is positively affected by its intangible capital intensity, then β_2, the coefficient for the interaction term between intangible investment and industry output share growth, should be positive.

5.4.2 Firm Level Regression Results

Table 11 reports the regression results of Equation 19. The 1st column under each dependent variable heading reports the baseline results when intangible investment is taken as exogenous. The

[21] This proposition can be formally proved with the baseline model extended to allow for multiple firms in each sector. Since it is not essential to the paper's thesis, the extended model and proof are not included here and are available from the author upon request.

[22] I also estimated the model setting $grow_j$ as industry's employment share growth. The results are qualitatively similar.

[23] In the data, newly listed firms' SG&A are often much higher than the average level. This may be due to one-time expenditures related to changing firm status, which is not related to intangible investment. Thus in the estimation I only include firms that are listed for ≥ 5 year.

assumption of exogenous investment may be challenged if, for example, better growth opportunity of a firm leads to both higher current period investment and higher future growth. However, notice that the potential simultaneity will most likely only decrease the chance of finding a positive β_2.[24] Nevertheless, I estimated Equation 19 treating $\left(\frac{SG\&A}{Sales}\right)_{ij,t-1}$ as endogenous and using five-period lagged SG&A to Sales ratio as instrument. The result is reported in the 2nd column under each dependent variable heading. Finally, the 3rd and 6th column of Table 11 report results with physical capital investment level and its interaction with industry growth added as regressors.

	Sales Growth			Employment Growth		
	Baseline	IV	physical investment	Baseline	IV	physical investment
SG&A/Sales	0.033***	-0.019	0.033***	-0.058***	0.004	-0.059***
	(0.005)	(0.013)	(0.005)	(0.005)	(0.014)	(0.005)
(SG&A/Sales) × grow	0.036***	0.034**	0.038***	0.013**	0.047***	0.016**
	(0.005)	(0.014)	(0.005)	(0.006)	(0.014)	(0.006)
I_K/Sales			0.005***			0.000
			(0.001)			(0.001)
(I_K/Sales) × grow			-0.003**			-0.002
			(0.001)			(0.002)
age	-0.081***	-0.001***	-0.085***	-0.063***	-0.002***	-0.062***
	(0.008)	(0.000)	(0.009)	(0.010)	(0.000)	(0.011)
log(total asset)	0.262***	0.129***	0.260***	0.042***	0.035***	0.043***
	(0.003)	(0.002)	(0.003)	(0.003)	(0.003)	(0.003)
log(total revenue)	-0.385***	-0.133***	-0.382***	-0.143***	-0.034***	-0.144***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
r2	0.193	0.072	0.194	0.050	0.022	0.049
N	126470	106020	122763	115678	98580	113259

Table 11: Intangible investment, firm growth, and industry growth

Across all specifications, the interaction term between SG&A and industry growth is positive and significant at either 1% or 5% level. Treating intangible investment as endogenous does not significantly change the magnitude of the coefficient for the interaction term in the sales growth regression, and increases the value of the coefficient in the employment growth regression. Therefore, the results generally confirm the hypothesis that output growth is higher for industries in

[24] The reason is the following. A favorable exogenous shock to the future period will lead to increasing investment in the current period, if the firm foresees the shock, and higher future growth as well. In that case, the estimated coefficient for the intangible investment variable will be inflated. However, the shock will only downward bias the coefficient for the interaction term between intangible investment and industry growth, assuming the distribution of shocks is the same across industries. This is because that for the same level of shock, the firms in the growing, high intangible capital industries will choose to raise SG&A investment more than the firms in the low intangible industries, as intangible capital is a more important input for the former. Other things equal, that will lower the association between SG&A and growth for firms in the growing high intangible industries compared to firms in low intangible industries, thus works against our goal of finding a positive β_2.

which intangible capital has a larger impact on firm growth. One way to perceive the magnitude of the cross-industry difference in intangible capital's significance is the following. The industry at the 20th percentile of output growth is "Primary Metal", while the industry at the 80th percentile is "Non-bank Credit Institutions". According to the estimates of β_1 and β_2 in the 3rd specification of the sales growth regression, the level and variation of intangible investment explains only 0.9 percent of the firm growth and cross-firm growth differentials in the Primary Metal industry, while intangible capital accounts for 10% of the level and variation of firm growth in the Credit Institution industry.

Contrasting the results for intangible capital, the coefficient for the interaction term between physical capital investment and industry growth is negative and significant in the sales growth regression, and negative but insignificant in the employment growth regression. These results indicate that physical capital seems to have a decreasing impact on firm growth in the expanding industries.

5.4.3 Robustness Check

In this section, I conduct several robustness checks to test how sensitive the results of the baseline regression of Equation 19 are to additional restrictions. First, I check if the impact of intangible investment on firm growth is driven by the investment related to R&D. There is a long literature on the productivity-enhancing effect of research and development activities, which is probably the most widely recognized type of intangible capital investment. Since the knowledge assets accumulated through investment in R&D is part of a firm's intangible capital, it raises the concern of whether it is only the R&D-related part of SG&A expenditure that has an impact on firm growth. This question is ultimately about the robustness of the concept of intangible capital itself. Therefore to differentiate R&D's impact from that of other intangible investments, I augment Equation 19 with firms' R&D expenses over sales, and its interaction with industry output share growth.

Besides using IV, a second way to correct the endogeneity caused by unobserved exogenous factors is to explicitly include in the estimation equation variables that would capture these factors. Although a firm's growth potential is not directly observable, financial market data can often reveal valuable information about it. Specifically, assuming that different firms are faced with different growth opportunities and the information regarding future growth is reflected in the firm's current stock price, I add in Equation 19 a firm's average price to book ratio in year $t-1$ as a measure for the unobserved influences on the firm's future growth.

The results with additional controls are presented in Table 12. Column 1 and 3 report regression results when R&D controls are added. The variable "R&D/Sales" and its interaction with industry share growth are positive and significant in the firm sales growth regression, which indicates that R&D does creates productive assets and R&D capital is more important in the expanding industries. However, neither of the two variables are significant in the employment growth regression. The lack of influence of R&D on the employment composition is probably due to the fact that the R&D workforce is highly specialized and small in quantity. On the other hand, the signs and magnitudes of SG&A variables do not significantly change after adding R&D controls. Therefore, the baseline results do not seem to be driven by the R&D part of intangible capitals.

The 2nd and 4th Columns of Table 12 present results with firm's price-to-book ratio added as control variable. The P/B ratio is positive and significant in both sales growth and employment growth regressions, suggesting that financial market data does incorporate information about firms' future growth prospect. In the sales growth regression, the intangible investment variable and its interaction with industry growth remain positive and significant, though the coefficients are now lower than in the baseline estimation. For the employment growth regression, the intangible investment interaction term maintains its positive sign and significant level, and its coefficient is even higher than before. Overall, the message of Table 12 is one of the relative robustness of the relationship between intangible capital intensity and industry growth to additional restrictions.

	Sales growth		Employment growth	
	Adding R&D	Adding P/B ratio	Adding R&D	Adding P/B Ratio
SG&A/Sales	0.032***	0.018***	-0.087***	-0.085***
	(0.007)	(0.006)	(0.008)	(0.007)
(SG&A/Sales) × grow	0.049***	0.029***	0.050***	0.026***
	(0.009)	(0.007)	(0.010)	(0.008)
I_K/Sales	0.017***	0.001	0.001	-0.001
	(0.004)	(0.001)	(0.004)	(0.001)
(I_K/Sales) × grow	-0.029***	0.002	-0.004	0.000
	(0.005)	(0.001)	(0.005)	(0.002)
R&D/Sales	0.026***		-0.009	
	(0.005)		(0.006)	
(R&D/Sales) × grow	0.042***		0.010	
	(0.007)		(0.009)	
price to book ratio		0.062***		0.055***
		(0.002)		(0.002)
age	-0.109***	-0.154***	-0.028	-0.119***
	(0.031)	(0.016)	(0.034)	(0.019)
log(total asset)	0.203***	0.273***	0.024***	0.055***
	(0.004)	(0.004)	(0.005)	(0.004)
log(total sales)	-0.329***	-0.393***	-0.127***	-0.160***
	(0.005)	(0.003)	(0.005)	(0.004)
r2	0.182	0.204	0.047	0.062
N	60413	90868	57541	86461

Table 12: Intangible investment, firm growth and industry growth: additional controls

Besides adding additional controls, I also look at whether the baseline results are sensitive to the choice of time period. Table 13 reports the estimation results of Equation 19 when I break the sample data into two sub-periods: 1950 to 1978 and 1979 to 1997. The interaction term between intangible investment level and industry growth is positive and significant only for the second sub-period. For the earlier sub-period, the interaction term is positive but insignificant in the sales growth regression, and negative in the employment growth regression. These results seem to indicate that the structural change driven by intangible capital accumulation is still a fairly contemporary phenomenon, and the impact of intangible capital on industry growth has increased over time.

All in all, the empirical results with firm data are generally consistent with the prediction of the model regarding the relationship between intangible capital intensity and industry growth. The results are robust to most of the additional sensitivity checks.

	1950 - 1978		1979 - 2007	
	Sales growth	Employment growth	Sales growth	Employment growth
SG&A/Sales	-0.028	0.012	-0.001	-0.078***
	(0.021)	(0.028)	(0.006)	(0.006)
(SG&A/Sales) × grow	0.012	-0.183***	0.043***	0.020***
	(0.024)	(0.037)	(0.006)	(0.007)
I_K/Sales	0.097***	-0.011	0.003***	-0.001
	(0.009)	(0.012)	(0.001)	(0.001)
(I_K/Sales) × grow	-0.007	-0.014	-0.002	-0.001
	(0.010)	(0.013)	(0.001)	(0.002)
age	0.006	0.025	-0.118***	-0.091***
	(0.016)	(0.018)	(0.011)	(0.013)
log(total asset)	0.145***	-0.023***	0.294***	0.041***
	(0.006)	(0.007)	(0.004)	(0.004)
log(total sales)	-0.309***	-0.105***	-0.458***	-0.177***
	(0.006)	(0.007)	(0.004)	(0.004)
r2	0.185	0.076	0.224	0.053
N	38137	33886	84626	79373

Table 13: Intangible investment, firm growth and industry growth: different time periods

6 An Application: Intangible Capital and the Rise of Service Sector

The aggregate economy can be divided into goods-producing and service-producing sectors, if we classify industries according to the nature of their outputs. It is a well-known fact that in the recent decades, the service sector has expanded relative to the goods-producing sector in both real output and employment. Figure 7 documents this fact.

As an application of the paper's theory, the rise of the service sector can be explained by examining the intangible capital intensities of service industries. First of all, if we examine industry data in more details, it is easy to see that contrary to the popular perception, not all service industries are expanding. Table 14a and 14b list respectively the service industries whose real value added shares in total economy have increased and decreased over the period of 1977 − 2007, based on consistent NAICS classification.

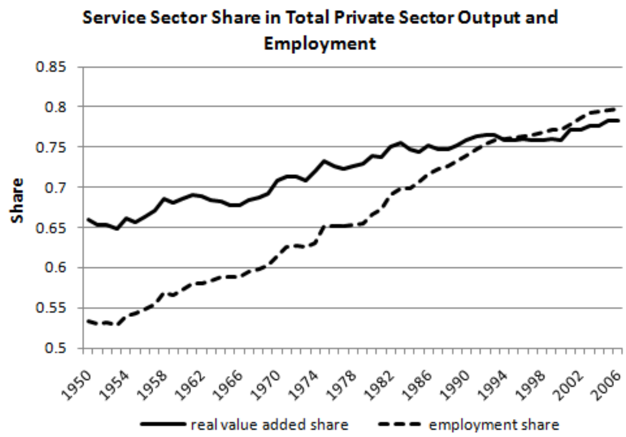

Figure 7: Service Sector Share of Real Output and Employment

Further examining the growing service industries, we can see that the growing part of the service sector consists of primarily intangible capital intensive industries. Here as before, I divide industries into high and low intangible capital groups according to whether the industry's SG&A to sales ratio is higher than the cross-industry median. Table 14a and 14b also report the intangible capital intensity of each service industry and the industry group they belong to. Figure 7 plots the real value added share growth rates of all service industries from 1977 to 2007 against their intangible capital intensities over the same period.

High Intangible & Growing Service Industries			
Industry	Intangible Capital Intensity	Real Value Added Share	
		1977	2007
Wholesale trade	0.170	0.047	0.067
Retail trade	0.250	0.060	0.090
Warehousing and storage	0.190	0.002	0.003
Publishing industries (includes software)	0.492	0.009	0.014
Motion picture and sound recording industries	0.208	0.003	0.004
Broadcasting and telecommunications	0.245	0.017	0.040
Information and data processing services	0.222	0.002	0.009
Securities, commodity contracts, & investments	0.378	0.001	0.028
Professional, scientific, and technical services	0.230	0.028	0.058
Computer systems design and related services	0.352	0.003	0.017
Administrative and support services	0.200	0.015	0.029
Ambulatory health care services	0.217	0.041	0.041
	Total share:	0.227	0.398

Low Intangible & Growing Service Industries			
Industry	Intangible Capital Intensity	Real Value Added Share	
		1977	2007
Air transportation	0.099	0.003	0.009
Truck transportation	0.048	0.010	0.010
Rental and leasing services and	0.153	0.008	0.011
Social assistance	0.110	0.003	0.008
Performing arts, sports, museums, etc	0.117	0.003	0.005
Amusements, gambling, and recreation	0.156	0.005	0.006
Food services and drinking places	0.098	0.019	0.020
	Total share:	0.051	0.067

Table 14a: IC Intensity of Growing Service Industries (1977-2007)

High Intangible & Declining Service Industries			
Industry	Intangible Capital Intensity	Real Value Added Share	
		1977	2007
Federal Reserve banks, credit intermediation, etc	0.218	0.051	0.040
Legal services	0.260	0.020	0.013
Waste management and remediation services	0.171	0.003	0.003
Educational services	0.363	0.011	0.009
Other services, except government	0.257	0.038	0.023
	Total share:	0.123	0.087

Low Intangible & Declining Service Industries			
Industry	Intangible Capital Intensity	Real Value Added Share	
		1977	2007
Utilities	0.066	0.027	0.020
Rail transportation	0.061	0.004	0.003
Water transportation	0.086	0.001	0.001
Transit and ground passenger transportation	0.110	0.004	0.002
Pipeline transportation	0.047	0.002	0.001
Other transportation and support activities	0.114	0.007	0.007
Insurance carriers and related activities	0.126	0.034	0.025
Funds, trusts, and other financial vehicles	0.012	0.003	0.001
Real estate	0.021	0.136	0.125
Hospitals and nursing and residential care facilities	0.089	0.038	0.026
Accommodation	0.152	0.014	0.009
	Total share:	0.268	0.219

Table 14b: IC Intensity of Declining Service Industries (1977-2007)

Table 14a-b show that the growing part of the service sector is dominated by intangible capital intensive industries. In 2007, the high-intangible-capital industries, e.g., retail, publishing, investment and computer design services, constitute about 86% of the total real value-added share of the growing service sector. In contrast, the declining part of the service sector mostly consists of industries that are less intangible capital intensive, such as utilities and water/ rail/ pipeline transportations. These low intangible capital industries constitute 72% of the declining service sector's total value-added share in 2007. Figure 8 further confirms this trend. When service industry real value-added share is regressed upon industry intangible capital intensity, the regression coefficient is positive and highly significant.

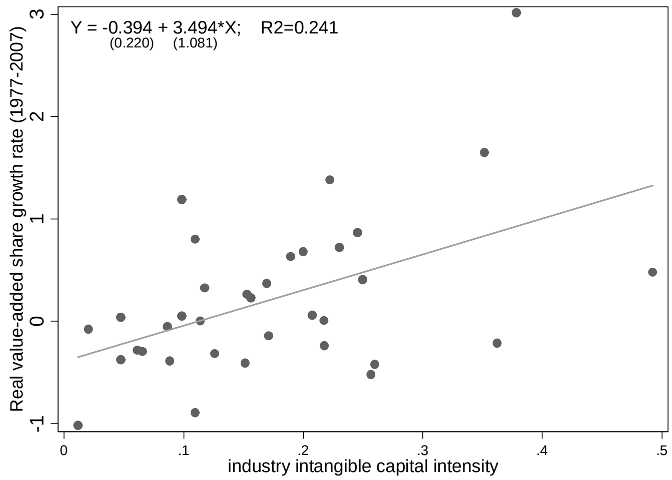

Figure 8: Service Inudustries' Growth and Intangible Capital Intensity

7 Conclusion

This paper explores the relationship between sectoral structural change in US economy during the recent decades and rise of intangible capital accumulation. I argue that as the economy relies more and more on knowledge and information assets in creating values, the differences in intangible capital accumulation across sectors will lead to structural change in terms of output and employment compositions of the economy. In the two-sector model of the paper, the importance of intangible capital in the production function differs across sectors and increases at different rates overtime. There are two kinds of work tasks in this economy: directly producing sectoral goods and producing intangible capital investment goods. When intangible capital's shares in the sectoral production functions increase, both sectors invest more in intangible capital, and the output and employment of the high intangible sector grow faster than those of the other sector.

The implications of the model are generally consistent with the stylized facts about structural change and intangible capital accumulation in the US since the 1950s. The calibrated model is able to replicate the following empirical facts: (1) increasing output and employment shares of the high intangible capital sector since the 1950s'; (2) increasing intangible investments in both sectors; (3) increasing employment share of occupations engaging in intangible investment work; (4) decreasing labor productivity growth for both sectors over the sample period, especially for the high intangible capital sector.

In addition, the model suggests that the conventional calculation of labor productivity– output over total labor input– may underestimate the real productivity in sectoral goods and services production, due to the fact that part of the sectoral labor force is allocated to intangible investment instead of direct production. This underestimation is more severe for the growing, high intangible sector.

Empirically, I test the relationship between intangible capital accumulation and structural change with industry and firm data. The industry-level estimation results show that future industry growths in real output and employment are significantly and positively correlated with industries' intangible capital intensities. The estimation is robust to other industry characteristics that might influence industry growth, such as human capital intensity, physical capital intensity and IT investment intensity. The firm-level result shows that the expanding industries are those where firms' intangible investment has a higher impact on firm growth. The result from a more disaggregate level confirms the thesis of the paper, that intangible capital is a driving force of industry/sector growth in a modern knowledge economy.

Finally, data shows that the growing part of the service sector is dominated by the high intangible industries. Thus the theory developed in the paper can also help to explain the rise of service sector in the recent decades,

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A Appendix

A.1 Solving the Planner's Problem

The Lagrangian for the social planner's problem is

$$\begin{aligned}\mathcal{L} \;=\; & \sum_{t=0}^{\infty}\beta^t\{\ln(C_t)+\lambda_t[Y_{1t}^{\gamma_1}Y_{2t}^{\gamma_2}-C_t-\frac{K_{t+1}^{1/\delta}}{K_t^{(1-\delta)/\delta}}]+\sum_{i=1,2}\mu_{it}[K_{i,t}^{a_i}O_{i,t}^{b_i}L_{y_i,t}^{1-a_i-b_i}-Y_{i,t}] \\ & +\sum_{i=1,2}\eta_{it}[(1-\varphi)\,O_{i,t}+B_{i,t}O_{i,t}^{1-d}L_{o_i,t}^{d}-O_{i,t+1}]+\phi_t(K_t-K_{1,t}-K_{2,t}) \\ & +\theta_t(L_t-L_{y_1,t}-L_{y_2,t}-L_{o_1,t}-L_{o_2,t})\end{aligned}$$

The first order conditions are:

$$C_t: \quad \lambda_t = 1/C_t \tag{20}$$

$$Y_{it}: \quad \mu_{it} = \lambda_t\gamma_i\frac{Y_t}{Y_{it}} \tag{21}$$

$$K_{it}: \quad \phi_t = \mu_{it} a_i \frac{Y_{it}}{K_{it}} \tag{22}$$

$$L_{y_i,t}: \quad \theta_t = \mu_{it}\left(1 - a_i - b_i\right) \frac{Y_{it}}{L_{y_i,t}} \tag{23}$$

$$L_{o_i,t}: \quad \theta_t = \eta_{it} d B_{it} O_{it}^{1-d} L_{o_i,t}^{d-1} \tag{24}$$

$$K_{t+1}: \; \frac{\lambda_t}{\delta} \frac{K_t^{1-1/\delta}}{K_{t+1}^{1-1/\delta}} = \beta\left[\lambda_{t+1} \frac{1-\delta}{\delta} \frac{K_{t+2}^{1/\delta}}{K_{t+1}^{1/\delta}} + \phi_{t+1}\right] \tag{25}$$

$$O_{i,t+1}: \; \eta_{it} = \beta\left[\mu_{i,t+1} b_i \frac{Y_{i,t+1}}{O_{i,t+1}} + \eta_{i,t+1}\left((1-\varphi) + (1-d) B_{i,t+1} O_{i,t+1}^{-d} L_{o_i,t+1}^{d}\right)\right] \tag{26}$$

Let $S_c = C_t/Y_t$. Combining Equation 20, 25, 22, and 21, we have

$$(1 - S_c) = \beta(1-\delta)(1-S_c) + \beta\delta\left(\gamma_1 a_1 + \gamma_2 a_2\right)$$

Therefore,

$$S_c = 1 - \frac{\beta\delta(\gamma_1 a_1 + \gamma_2 a_2)}{1 - \beta(1-\delta)}.$$

From Equation 23, 24, and 21, we get

$$\eta_{it} = \lambda_t \frac{Y_t}{L_{y_i,t}} \frac{\gamma_i\left(1 - a_i - b_i\right)}{d B_{it} O_{it}^{1-d} L_{o_i,t}^{d-1}} \tag{27}$$

Plug (27) into Equation 26 and rearrange:

$$\frac{(1-a_{it}-b_{it}) L_{o_i,t}^{1-d}}{d B_{it} O_{i,t}^{1-d} L_{y_i,t}} = \frac{\beta(1-\varphi)(1-a_{i,t+1}-b_{i,t+1}) L_{o_i,t+1}^{1-d}}{d B_{i,t+1} O_{i,t+1}^{1-d} L_{y_i,t+1}} + \frac{\beta(1-d)(1-a_{i,t+1}-b_{i,t+1}) L_{o_i,t+1}}{d O_{i,t+1} L_{y_i,t+1}} + \frac{\beta b_{i,t+1}}{O_{i,t+1}}$$

A.2 Proof of Proposition 3

From Equation 11 and Equation 7, the ratio between the two sectors' total employments can be written as

$$\frac{L_1}{L_2} = \frac{\gamma_1}{\gamma_2} \frac{\frac{\beta b_1 d\left(g_{B_1}+\varphi\right)}{(1-\beta)\left(1+g_{B_1}\right)+\beta d\left(g_{B_1}+\varphi\right)} + (1 - a_1 - b_1)}{\frac{\beta b_2 d\left(g_{B2}+\varphi\right)}{(1-\beta)\left(1+g_{B_2}\right)+\beta d\left(g_{B_2}+\varphi\right)} + (1 - a_2 - b_2)} \tag{28}$$

It is easy to see that $\frac{L_1}{L_2}$ is an increasing function of g_{B_1}, and a decreasing function of g_{B_2}. Suppose $g_{B_1} = g_{B_2} = g_B$. Then Equation 28 can be rewritten as

$$\frac{L_1}{L_2} = \frac{\gamma_1}{\gamma_2} \frac{\beta b_1 d\left(g_B + \varphi\right) + \left(1 - a_1 - b_1\right)\left[\left(1-\beta\right)\left(1+g_B\right) + \beta d\left(g_B+\varphi\right)\right]}{\beta b_2 d\left(g_B + \varphi\right) + \left(1 - a_2 - b_2\right)\left[\left(1-\beta\right)\left(1+g_B\right) + \beta d\left(g_B+\varphi\right)\right]} \tag{29}$$

Taking derivative of Equation 29 with respect to g_B, we get

$$\frac{\partial\left(L_1/L_2\right)}{\partial g_B} = \frac{\gamma_1}{\gamma_2} \frac{\left[\left(1-a_2\right) b_1 - \left(1-a_1\right) b_2\right] \beta d\left(1-\beta\right)\left(1-\varphi\right)}{\left[\beta b_2 d\left(g_B+\varphi\right) + \left(1-a_2-b_2\right)\left(\left(1-\beta\right)\left(1+g_B\right) + \beta d\left(g_B+\varphi\right)\right)\right]^2}$$

Thus $\frac{\partial(L_1/L_2)}{\partial g_B} > 0 \Leftrightarrow \frac{b_1}{b_2} > \frac{1-a_1}{1-a_2}$.

Similarly, take derivative of Equation 29 with respect to b_1 :

$$\frac{\partial\left(L_1/L_2\right)}{\partial b_1} = \frac{\gamma_1}{\gamma_2} \frac{\left(-\frac{\partial a_1}{\partial b_1}\right)\left[\left(1-\beta\right)\left(1+g_B\right)+\beta d\left(g_B+\varphi\right)\right]-\left(1-\beta\right)\left(1+g_B\right)}{\beta b_2 d\left(g_B+\varphi\right)+\left(1-a_2-b_2\right)\left[\left(1-\beta\right)\left(1+g_B\right)+\beta d\left(g_B+\varphi\right)\right]}$$

Therefore, $\frac{\partial(L_1/L_2)}{\partial b_1} > 0 \Leftrightarrow \frac{\partial a_1}{\partial b_1} < \frac{(1-\beta)(1+g_B)}{(1-\beta)(1+g_B)+\beta d(g_B+\varphi)}$.