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Sectoral Structural Change in a Knowledge Economy

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Abstract

The sectoral composition of US economy has shifted dramatically in the recent decades. At the same time, knowledge and information capital has become increasingly important in modern production process. This paper argues that a ready explanation for the recent sectoral structural change lies in the difference of intangible capital accumulation across sectors. In the two-sector model of the paper, as the importance of intangible capital increases, labor is shifted from direct goods production to creating sector-specific intangible capital. In the process, the real output and employment shares of the high-intangible sector increase. The model generates sectoral composition change and labor productivity trend that reasonably match the data. It also shows that conventional labor productivity calculation understates the "true" productivity in sectoral goods production. The underestimation is greater for the growing sector.

The empirical regressions of the paper indicate a positive and significant association between intangible capital investment intensity and firms' future output and employment growth. The correlation is higher for firms in the growing sector. At the industry level, controlling for industry human capital intensity, physical capital intensity and IT investment level, intangible capital intensity is positively correlated with future industry real output and employment share growth. These findings are consistent with the implications of the model.

The paper also presents evidence suggesting that most growing service industries are intangible capital intensive. Thus the theory developed here can also help to reconcile the expansion of the service sector and the seemingly low productivity of the sector.

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 mean 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 had to 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 process.[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 investment and sectoral structural change during the same period. In the past several decades, the high-intangible-capital industries grow faster than their low-intangible-capital peers. In figure 1a, US SIC two-digit industries are divided into two sectors according to industry intangible capital investment intensity.[2] Figure 1a 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 overtime. Figure 1b shows the trend of 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.

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

[2] The methodology of sector classification will be reviewed in the calibration section of the model.

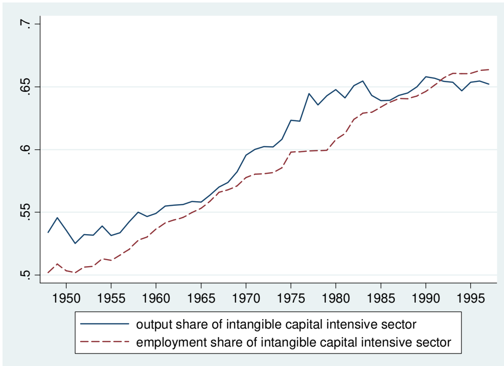

Figure 1a: Shares of the intangible capital intensive sector

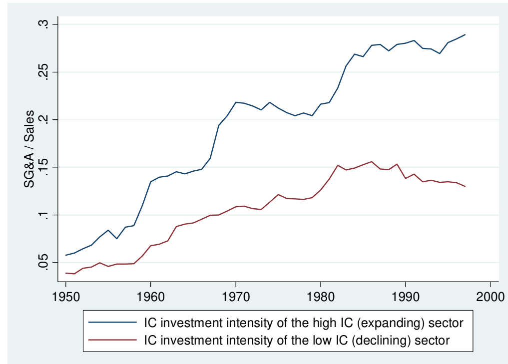

Figure 1b: Intangible capital investment trends

Besides the structural change in terms of sectoral composition, the employment composition of the economy has also been going through structural change– employment is now shifting from direct goods production to intangible capital investment activities. US employment by occupation data readily demonstrate this trend. The number of workers employed in occupations that are typically associated with intangible capital production, as a fraction of total workforce, is expanding. I divide these workers into three categories: 1) the workers whose jobs mainly involve creativity and innovation, such as engineers, architects, scientists, artists, and entertainers; 2) the workers who engage in organization construction and maintenance, such as managers, administrators, HR specialists, and business consultants; 3) the workers who fulfill marketing and communication tasks, such as advertising personnel, customer service representatives, and IT operators. Figure 2 indicates that the share of these workers whose major job task involves producing intangible capital has increased as a proportion of total working population.[3]

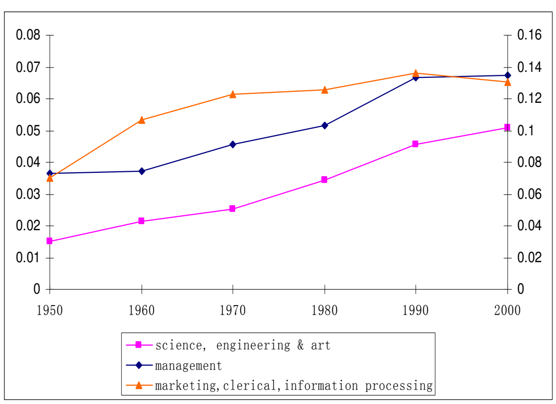

Figure 2: Rise of employment engaging in intangible capital investment

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

The fourth stylized fact is that the growing sector has a lower labor productivity growth on average than the declining sector. As shown in table 1, though the high intangible sector's productivity growth is higher for the 1949-1973 sub-period, overall the productivity growth is higher in the low intangible sector. At first sight, this fact seems to confirm 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 prediction from the assumption is that the expansion of the less productive service industries will eventually cause the growth of the whole economy to slow down. Since most expanding service industries are concentrated in the high intangible sector, the result in table 1 seems to be consistent with this assumption. However, as will be discussed in the calibration section of the paper, the conventional way to calculate labor productivity, i.e., output divided by employment, does not reflect the "true" productivity in goods and service production, since a considerable share of employment is engaged in intangible capital investment instead of direct production activities.

Annual Labor Productivity Growth (%)			
	1949-1973	1974-1997	1949-1997
High Intangible Sector	3.20	-0.94	1.17
Low Intangible Sector	2.49	0.72	1.62

Table 1: Labor productivity growth of the two sectors

The model of the paper accommodate all the stylized facts presented above. The calibration result shows that the model well matches the magnitude of structural change in US data. The model can generate the output share increase, and can explain about 65% of the employment share increase, of the intangible capital intensive sector from 1950 to 1997. The simulation of the model also produce predictions about the future trend of sectoral structural change under different assumptions of parameter values. It indicates that under certain assumptions, the trend of increasing employment share of intangible capital intensive sector can be reversed.

The empirical part of the paper uses firm-level and industry-level data to test the theory's implications. The result shows that firms' intangible investment is positively correlated with their output and employment growth, and this effect is stronger in the growing sector, which is more intangible capital intensive. At the industry level, the magnitude of industry intangible capital investment is positively correlated with future industry share growth in both real output and employment. These findings are consistent with the theory.

The rest of the paper is organized as follows. Section 2 gives a review of literature. Section 3 presents a two-sector model featuring intangible capital accumulation, discusses how the model generates sectoral structural change and analyzes the calibration results. Section 4 carries out empirical exercises to test the predictions of the model. Section 5 discusses how to interpret the rise of service sector over goods producing sector from the perspective of intangible capital accumulation. Section 6 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 of 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 task 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 industrial-age economy and modern knowledge economy is that cutting-edge production know-hows are 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, which 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 declining during the same period. Some researchers argue that an important source for the increase in firms' market capitalization is 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 invest at least $1 trillion annually in intangible assets, and 1/3 of US corporate assets are in intangibles. Corrado, Hulten and 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, amount 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.[4] 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 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:

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

where $\gamma_1 + \gamma_2 = 1$.

I assume that there is only one firm in each sector, and the sectoral goods production

[4] 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.

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 physical capital, intangible capital and labor used in producing sectoral goods Y_i. If $a_1 = a_2$ and $b_1 = b_2$, then the two sectoral production functions are identical and the model reduces to an one-sector economy. Factor shares in the production can shift over time. For example, $b_{i,t}$ can be different from $b_{i,t+s}$. And the magnitude of the change can be different for the two sectors.

Physical capital and labor are freely mobile across sectors. To simplify the inessential part of the model, I assume that physical capital accumulates according to the log-linear form

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

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

Intangible capital is accumulated within a sector and is not directly transferrable between the two sectors. It accumulates according to

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

where $X_{i,t}$ is the current period investment in sector i's intangible capital. Assuming that only labor input is required to produce the sectoral investment goods $X_{i,t}$, the production function for X_i is

$$X_{i,t} = B_{i,t} (L_{o_i,t})^d$$

d is a constant between 0 and 1, which depicts the decreasing return to scale in intangible capital production. $B_{i,t}$denotes the productivity level of sector i's intangible capital production at period t, which is exogenously given and grows at an annual rate, g_{B_i}: $B_{i,t} = B_{i,t-1}(1+g_{B_i})$.

Labor supply in the economy is inelastic and equal to the population size at time t, L_t. Capital and labor market clearing requires that

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

The economy admits a representative household with log utility

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

The household chooses $\{C_t, L_{y_1,t}, L_{y_2,t}, L_{o_1,t}, L_{o_2,t}\}_{t=0}^{\infty}$ to maximize its lifetime utility, subject to the budget constraint

$$C_t + I_t + q_{1t} X_{1t} + q_{2t} X_{2t} \leq w_t L_t + r_t^k K_t + r_t^{o_1} O_{1t} + r_t^{o_2} O_{2t},$$

and the capital accumulation rules and market clearing constraints for labor and physical capital. Here q_1, q_2 are the price of intangible investment goods in each sector.

The household's budget constraint coincides with the resource constraint of the economy

$$C_t + I_t \leq Y_t$$

If we normalize the price of the final good to 1, the equilibrium prices of the two sectoral goods can be denoted as

$$p_{1,t} = \gamma_1 \frac{Y_t}{Y_{1t}}, \qquad p_{2,t} = \gamma_2 \frac{Y_t}{Y_{2t}}$$

The wage rate, expressed relative to the final good price is

$$\begin{aligned} w_t &= (1 - a_i - b_i) \frac{Y_{i,t}}{L_{y_i,t}} \gamma_i \frac{Y_t}{Y_{i,t}} \\ &= (1 - a_i - b_i) \gamma_i \frac{Y_t}{L_{y_i,t}} \end{aligned}$$

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

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

From the first order conditions,[5] it can be derived that the ratio of physical capital allocated to the two sectors is constant. So is the ratio of labor used in producing sectoral goods:

$$\begin{aligned} \frac{K_{1,t}}{K_{2,t}} &= \frac{\gamma_1 a_1}{\gamma_2 a_2} \\ \frac{L_{y_1,t}}{L_{y_2,t}} &= \frac{\gamma_1 (1 - a_1 - b_1)}{\gamma_2 (1 - a_2 - b_2)} \end{aligned} \tag{2}$$

It is also easy to prove that the household always consumes a fixed proportion s_c of the final goods produced each period:

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

[5] Specified in the appendix.

3.2 Comparative Statics

The Euler equation for intangible capital accumulation in each sector can be written as

$$\frac{1-a_{it}-b_{it}}{dB_{it}}\frac{L_{o_i,t}^{1-d}}{L_{y_i,t}}=\beta(1-\varphi)\frac{1-a_{i,t+1}-b_{i,t+1}}{dB_{i,t+1}}\frac{L_{o_i,t+1}^{1-d}}{L_{y_i,t+1}}+\frac{\beta b_{i,t+1}}{O_{i,t+1}} \tag{3}$$

In the steady state, $O_i=\frac{B_iL_{o_i}^d}{g_{B_i}+\varphi}$. Equation 3 can be written as

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

from which it is easy to calculate the labor distribution within sector i:

$$\frac{L_{o_i}}{L_{y_i}}=\frac{\beta b_i d(g_{B_i}+\varphi)}{(1-a_i-b_i)(1+g_{B_i}-\beta+\beta\varphi)} \tag{4}$$

Proposition 1 *In the steady state,* $\frac{\partial(L_{o_i}/L_{y_i})}{\partial b_i}>0$, $\frac{\partial(L_{o_i}/L_{y_i})}{\partial g_{B_i}}>0$, *and* $\frac{\partial^2(L_{o_i}/L_{y_i})}{\partial g_{B_i}\partial b_i}>0$. *In other words, increases in b_i and g_{B_i} both lead to labor shifting from direct goods production to intangible capital production. And the effects of the changes in b_i and g_{B_i} on labor allocation reinforces each other.*
Proof. *Simply taking derivative of the right-hand-side of equation 4 with respect to b_i and g_{B_i}.* ■

The intangible investment cost in period t can be expressed as $w_tL_{o_i,t}$. The steady state investment cost to output ratio can be written as a function of exogenous parameters.

Proposition 2 *In the steady state, the intangible investment expense to output ratio in sector i is*

$$\frac{wL_{o_i}}{p_iY_i}=\frac{\beta d(g_{B_i}+\varphi)}{1+g_{B_i}-\beta+\beta\varphi}b_i \tag{5}$$

The ratio is an increasing function in b_i and g_{B_i}.

The considerable increase in intangible investment/output ratio since the 1950s, and the shift of employment towards "knowledge work" suggest that either the share of intangible capital in the production function b_i or the productivity of intangible investment g_{B_i} has increased, or both, assuming d and φ are constant over time. In the calibration section, both hypotheses will be examined.

The labor hired in sector i can be seen as the sum of labor engaged in sectoral goods production and in intangible capital creation: $L_i=L_{y_i}+L_{o_i}$. The following proposition summarizes the relationship between cross-sector labor allocation and intangible capital growth:

Proposition 3 *Sector 1's labor share $\frac{L_1}{L_1+L_2}$ increases with sector 1's intangible investment productivity g_{B_1}, and decreases with sector 2's intangible investment productivity g_{B_2}. If* *intangible investment productivity is the same for the whole economy:* $g_{B_1} = g_{B_2} = g_B$*, an increase in* g_B *leads to increase in* $\frac{L_1}{L_1+L_2}$ *if* $b_1 > b_2$ *and* $\frac{(a_2-a_1)(1-\beta+\beta\varphi)}{1-\beta+\beta\varphi-\beta\varphi d} < b_1 - b_2 < \frac{a_2-a_1}{1-\beta d}$*.* $\frac{L_1}{L_1+L_2}$ *is increasing in* b_1*, if in the production function, intangible capital substitutes physical capital instead of labor; i.e.,* $\Delta b_1 = -\Delta a_1$*, where* Δx *is the amount of increase in variable* x*.*

Proof. *See the appendix.* ■

It is also straightforward to show that when $b_1 > b_2$, sector 1's real output share $\frac{Y_1}{Y_1+Y_2}$ increases with g_B. In fact, if $g_B > 0$ and $b_1 > b_2$, the ratio $\frac{Y_1}{Y_1+Y_2}$ will go to 1 as $t \to \infty$. It is more difficult to reach an analytical solution of changes in $\frac{Y_1}{Y_1+Y_2}$ with respect to changes in b_1, b_2. However, as the calibration section will show, sector 1's real output share increases with Δb_1, provided that $\Delta b_1 > \Delta b_2$ and $\frac{|\Delta a_2|}{\Delta b_2} \leq \frac{|\Delta a_1|}{\Delta b1} \leq 1$.

3.3 Multiple Firms

The baseline model can be extended to include multiple firms in each sector. The results generated allow us to test the theory using firm-level data.

Following Rossi-Hansberg & Wright (2007), I assume that all firms in sector i share the same production function

$$y_{ji,t} = \left[k_{ji,t}^{a_i} o_{ji,t}^{b_i} l_{y_{ji},t}^{1-a_i-b_i}\right]^v - F_i \quad 0 < j \leq n_i, \tag{6}$$

where $0 < v < 1$, is the coefficient of decreasing return to scale; F_i is the sunk cost that a firm has to pay in each period in order to produce; n_i is the number of firms in sector i, which can be a non-interger. It can be shown that in the equilibrium, the aggregation of firm outputs leads to a constant returen to scale production function at the sectoral level, basically identical to the one in the baseline model. The proof is included in the appendix.

As in the baseline model, physical capital and labor are mobile across firms. Firms rent physical capital each period, but each firm must accumulate its own intangible capital:

$$\begin{aligned} o_{ji,t+1} &= (1-\varphi)\, o_{ji,t} + x_{ji,t} \\ x_{ji,t} &= \widetilde{B}_{ji,t}(l_{o_{ji},t})^d \end{aligned}$$

where x_i is a constant. $\widetilde{B}_{ji}$ is the intangible investment productivity of firm j in sector i.

It can be shown that in the steady-state equilibrium, the labor allocation within each firm in sector i is identical to equation 4:

$$\frac{l_{o_i}}{l_{y_i}} = \frac{\beta b_i d\varphi}{(1-a_i-b_i)(1-\beta+\beta\varphi)} \tag{7}$$

Here to simplify the result, the growth rate of intangible investment productivity is assumed to be zero.

Let $B_{ji} = \widetilde{B}_{ji}^{\frac{b_i v}{1-v+(1-d)b_i z}}$. From the first order conditions, it can be shown that in the equilibrium, the output and resource allocations within sector i are

$$\frac{y_{ji,t}}{Y_{i,t}} = \frac{k_{ji,t}}{K_{i,t}} = \frac{l_{y_{ji},t}}{L_{y_i,t}} = \frac{l_{o_{ji},t}}{L_{o_i,t}} = \frac{B_{ji,t}}{B_{i,t}} \tag{8}$$

where $B_{i,t} = \sum_{j=1}^{n_i} B_{ji,t}$ is the aggregation of all firms' productivity within the sector. $Y_i, K_i, L_{y_i}, L_{o_i}$ are sectoral level output, capital and labor respectively.

Now let's introduce firm-level stochastic factor into the model. Suppose each period $B_{ji,t}$ is randomly drawn from a distribution $G(B)$ with mean value normalized to 1. The draw is i.i.d across firms, and is known to the firm in period t. The productivity distribution is the same across the two sectors. Assuming that the number of firms in each sector is large enough and firm-level fluctuations cancel out with each other, the sectoral intangible investment productivity $B_{i,t}$ is not affected by individual firms' productivity change.

Firm j's Euler equation for intangible capital accumulation is

$$\frac{(1-a_i-b_i)}{d\widetilde{B}_{ji,t-1}} \frac{y_{ji,t-1}}{Y_{i,t-1}} \frac{l_{o_{ji},t-1}^{1-d}}{l_{y_{ji},t-1}} = \beta(1-\varphi) \frac{(1-a_i-b_i)}{d\widetilde{B}_{ji,t}} \frac{y_{ji,t}}{Y_{i,t}} \frac{l_{o_{ji},t}^{1-d}}{l_{y_{ji},t}} + \beta b_i \frac{y_{ji,t}}{Y_{i,t}} \frac{1}{o_{ji,t}}$$

Log linearizing the equation around the steady state:

$$\begin{aligned} & \frac{(1-a_i-b_i)}{d} \frac{\bar{l}_{o_{ji}}}{\bar{l}_{y_{ji}}} \left[\widehat{y}_{ji,t-1} - \widehat{Y}_{i,t-1} + (1-d)\,\widehat{l}_{o_{ji},t-1} - \widehat{l}_{y_{ji},t-1} - \widehat{B}_{ji,t-1}\right] \qquad (9) \\ = \;& \beta(1-\varphi) \frac{(1-a_i-b_i)}{d} \frac{\bar{l}_{o_{ji}}}{\bar{l}_{y_{ji}}} \left[\widehat{y}_{ji,t} - \widehat{Y}_{i,t} + (1-d)\,\widehat{l}_{o_{ji},t} - \widehat{l}_{y_{ji},t} - \widehat{B}_{ji,t}\right] + \beta b_i \varphi \left(\widehat{y}_{ji,t} - \widehat{Y}_{i,t} - \widehat{o}_{ji,t}\right) \end{aligned}$$

where $\widehat{x} = \ln(x) - \ln(\overline{x})$, where $\overline{x}$ is the steady-state value of variable x. Assume that at time $t-1$, firm j is in the steady state, that is, $\widehat{y}_{ji,t-1}, \widehat{l}_{o_{ji},t-1}$, and $\widehat{l}_{y_{ji},t-1}$ are all equal to zero. Plug equation 7 into equation 9 and rearrange. We have

$$\widehat{l}_{o_{ji},t} = \frac{1}{1-d}\widehat{B}_{ji,t}$$

In other words, the change in $l_{o_{ji},t}$ in response to a shock in $\widetilde{B}_{ji,t}$ is linear. Notice that the relationship does not depend on b_i. So the investment response function is the same for firms in both sectors. The output change after the $\widetilde{B}_{ji,t}$ can be written as

$$\widehat{y}_{ji,t+1} - \widehat{y}_{ji,t} = \frac{b_i v}{1-(1-b_i)\,v} \left(\widehat{o}_{ji,t+1} - \widehat{o}_{ji,t}\right)$$

Since $\widehat{y}_{ji,t}$ and $\widehat{o}_{ji,t}$ both equal zero, and $\widehat{o}_{ji,t+1} = (1-\varphi)\,\widehat{o}_{ji,t} + \widehat{B}_{ji,t} + d\widehat{l}_{o_{ji},t}$, the above equation can be rearrange as

$$\widehat{y}_{ji,t+1} = \frac{b_i v}{(1-d)\,(1-v+b_i v)} \widehat{B}_{ji,t} \tag{10}$$

It is straightforward to see that the change in $y_{ji,t+1}$ in response to the $\widehat{B}_{ji,t}$ shock is an increasing function in b_i. It can be proved that the magnitude of $l_{ji,t+1}$'s response to $\widehat{B}_{ji,t}$ shock is also increasing in b_i. Too see this, first notice that $\widehat{l}_{ji,t+1} = \widehat{l}_{y_{ji},t+1} + \widehat{l}_{o_{ji},t+1}$. From equation 8, it is clear that $\widehat{l}_{y_{ji},t+1} = \widehat{y}_{ji,t+1}$. Assuming $\widehat{B}_{ji,t} = 0$, updating equation 9 one period forward and rearranging, we have

$$\widehat{l}_{o_{ji},t+1} = \frac{1-\beta+\beta\varphi}{\beta(1-\varphi)(1-d)}\left(\widehat{y}_{ji,t+1} - \widehat{o}_{ji,t+1}\right) \tag{11}$$

Log-linearizing the production function and the resource allocation equation 8:

$$\widehat{y}_{ji,t+1} = \frac{b_i v}{1-v+b_i v}\widehat{o}_{ji,t+1} \tag{12}$$

Plug equation 12 and 10 into equation 11 to obtain an expression of $\widehat{l}_{o_{ji},t+1}$ as a function of only preset parameters and $\widehat{B}_{ji,t}$:

$$\widehat{l}_{o_{ji},t+1} = \frac{(v-1)(1-\beta+\beta\varphi)}{\beta(1-\varphi)(1-v+b_i v)(1-d)^2}\widehat{B}_{ji,t}$$

$\widehat{l}_{ji,t+1}$, in turn can be written as

$$\widehat{l}_{ji,t+1} = \frac{1}{(1-v+b_i v)(1-d)}\left[b_i v - \frac{(1-v)(1-\beta+\beta\varphi)}{\beta(1-\varphi)(1-d)}\right]\widehat{B}_{ji,t}$$

It is clear by simply taking derivative of the expression with respect to b_i that the change of $\widehat{l}_{ji,t+1}$ in response to $\widehat{B}_{ji,t}$ is increasing in b_i.

Proposition 4 *The magnitudes of firm output and employment changes $\widehat{y}_{ji,t+1}$ and $\widehat{l}_{ji,t+1}$ in response to $\widetilde{B}_{ji,t}$ shock are increasing in b_i, while the change in intangible investment $w_t\widehat{l}_{o_{ji},t}$ in response to $\widetilde{B}_{ji,t}$ does not depend on b_i.*

This proposition generates testable predictions. Though $\widetilde{B}_{ji,t}$ shock is not directly observed in data, the magnitude of intangible investment has a one-to-one relationship with the level of $\widetilde{B}_{ji,t}$ and can be used as a signal for the latter. According to proposition 4, the output and employment growth next period associated with a positive $\widetilde{B}_{ji,t}$ should be higher in the growing sector, which has a higher b_i.

4 Calibration

4.1 Baseline Calibration

In this section, I carry out a calibration exercise to see whether the dynamics generated by the model can sufficiently account for the structural change patterns in US data.

First, let me explain the construction of figure 1 in more details. The data used is from BEA and COMPUSTAT North America. I divide SIC two-digit industries into two sectors:

that of high and low intangible-capital intensities. I use firms' sales, general & administrative expenditure as an approximation of intangible capital investment. (I will say more about this choice in the empirical data section later.) The intangible capital intensity is measured by SG&A expenditure-over-sales ratio, for a firm, and by the median firm SG&A/sales ratio, for an industry. I then use the time average industry intangible-capital intensity from 1950 to 1997 to categorize industries into the two sectors. Since firms' financial data are taken from COMPUSTAT database, it only includes publicly-traded companies, which contribute to, on average, over 50% of aggregate output of the economy.

Table 2 lists the sector categorization for SIC two-digit industries. As Figure 1a has shown, the high intangible-capital sector has experienced more rapid growth since the 1950s in both real output and employment.

Industry	Sector	intangible capital intensity
Coal mining	Low	0.063494
Primary metal	Low	0.079919
Textile mill products	Low	0.101019
Petroleum refining	Low	0.101929
Water transportation	Low	0.103739
Nonmetallic minerals	Low	0.104843
Motor freight transportation and warehousing	Low	0.10541
Construction	Low	0.110179
Paper and allied products	Low	0.114192
Transportation equipment	Low	0.114804
Railroad transportation	Low	0.121236
Metal Mining	Low	0.122902
Stone, clay, glass and concrete products	Low	0.127876
Transportation services	Low	0.135421
Electric, gas and sanitary services	Low	0.138873
Lumber and wood products	Low	0.139701
Insurance carriers	Low	0.141403
Agriculture	Low	0.14591
Wholesale trade	Low	0.147198
Air transportation	Low	0.149063
Fabricated metal	Low	0.158845
Rubber and plastics	Low	0.160539
Oil and gas extraction	Low	0.166757
Amusement and recreation services	Low	0.169068
Hotels and lodging places	Low	0.171884
Holding and other investment offices	Low	0.174578

Industry	Sector	intangible capital intensity
Automotive repair and services	High	0.176185
Furniture and fixtures	High	0.179072
Apparel and fabrics	High	0.185981
Food products	High	0.191736
Electronics	High	0.203104
Health services	High	0.206417
Motion pictures	High	0.207322
Leather and leather products	High	0.209435
Machinery & computer equipment	High	0.213644
Retail trade	High	0.223626
Miscellaneous manufacturing	High	0.225562
Communications	High	0.229593
Real estate	High	0.233641
Engineering, accounting, research, management and related	High	0.237746
Tobacco products	High	0.23897
Personal services	High	0.241167
Non-depository institutions	High	0.245592
Local and suburban transit	High	0.250251
Depository institutions	High	0.253257
Security and commodity brokers	High	0.260861
Measuring, analyzing and controlling instruments	High	0.274682
Printing, publishing and allied industries	High	0.281171
Chemicals and allied products	High	0.283856
Business Services	High	0.284404
Insurance agents, brokers and service	High	0.306434
Miscellaneous repairs	High	0.315063
Educational services	High	0.417472

Table 2: Sector categorization according to intangible capital intensity (1950-1997)

I assume that the initial year $t = 0$ corresponds to the year 1948 in reality, when SIC-2 digit industry output and employment data was was first available. COMPUSTAT firm data started in 1950. I assumed that the economy was initially in a steady state and used the SG&A/Sales ratio in 1950 to calculate the initial b_1 and b_2. The initial labor supply L_0 is normalized to 500. In the baseline calibration, I set the productivity of intangible capital production at t_0 to be the same in both sectors:$B_{1,1948} = B_{2,1948} = 1$. I will investigate alternative assumptions of these parameters in the sensitivity analysis section later.

The rest of the parameters that need to be decided–8 in all– are the following: β, $\{d, \gamma_i, a_i\}_{i=1,2}$, δ, φ. Physical capital's shares in the sectoral production functions are both set as $(0.5 - b_{1,old})$ and $(0.5 - b_{2,old})$ for the initial period. For periods beyond t_0, $a_{1,t} = a_{1,1948} - (b_{1,t} - b_{1,1948})$, $a_{2,t} = a_{2,1948} - 0.7\,(b_{2,t} - b_{2,1948})$. No estimation is available for the depreciation rate of intangible capital. Following related literature, I choose $\varphi = 0.5$. Physical capital's depreciation rate is set at the standard value $\delta = 0.08$. Sectors' shares in the utility function,γ_1 and γ_2 are chosen so that the output shares of the two sectors at t_0 is roughly the same as those in the data for the year 1948. This leads to $\gamma_1 = 0.51$ and $\gamma_2 = 0.49$. d_i, the measure of decreasing return to scale for intangible capital investment is assumed to be 0.8 for both sectors.

To calibrate intangible capital's share in the production function b_1 and b_2, recall from equation 5 that in the steady state,

$$b_i = \frac{q_i X_i}{p_i Y_i} \frac{1 + g_{B_i} - \beta + \beta\varphi}{\beta d\,(g_{B_i} + \varphi)} \tag{13}$$

In other words, b_i can be written as a function of intangible investment to output ratio and other parameters. In the first simulation exercise, I assumed that the economy was in the old steady state in 1948. For exogenous reasons such as production technology change, b_1 and b_2 experience one-time increases in the subsequent year. The economy then gradually transits to the new steady state. Using SG&A/Sales ratio as approximation of intangible investment to output ratio, the old and new b_i are identified by plugging sector-average SG&A/Sales ratio of 1948 and of 1997 into equation 13.[6] g_B is assumed to equal to zero in the baseline simulation. The intangible capital's shares calibrated this way are: $b_{1,old} = 0.077$, $b_{2,old} = 0.053$, $b_{1,new} = 0.393$, $b_{2,new} = 0.162$. In sum, the parameters used in the simulation are

β	L	d	B_{i,t_0}	γ_1	γ_2	δ	φ	$b_{1,old}$	$b_{2,old}$	$a_{1,old}$	$a_{2,old}$	$b_{1,new}$	$b_{2,new}$	$a_{1,new}$	$a_{2,new}$	g_{B_i}
0.96	500	0.8	1	0.51	0.49	0.08	0.5	0.077	0.053	0.423	0.447	0.393	0.162	0.107	0.371	0

[6] That is, the investment/output ratio in 1997 is assumed to be close enough to the "new" steady state.

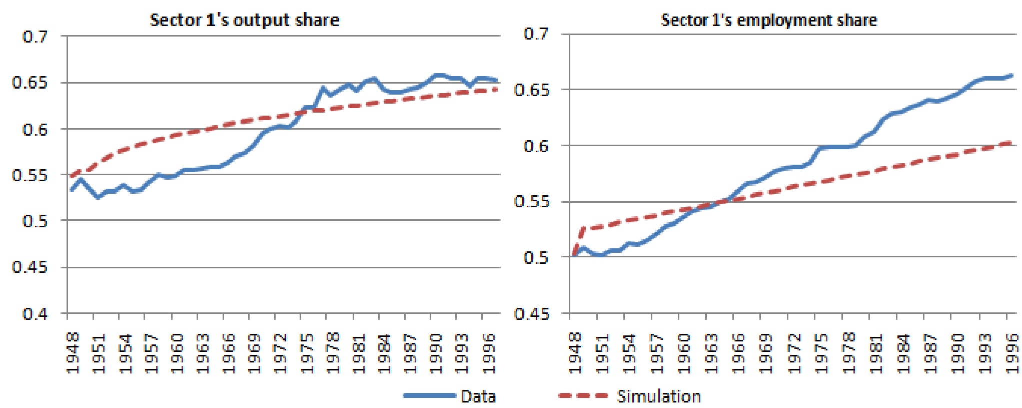

Figure 3

Figure 3 displays the simulation results for the output and employment shares of sector 1– the intangible capital intensive sector– in 50 years, with the parameter values specified above. For comparison, the empirical data is plotted in the same graph. Notice that the shares of sector 1 in both output and employment have increased significantly during this period. In the model, sector 1's output share went from 0.548 to 0.643, basically the same as in the data. On the employment side, the share of sector 1 rose from 0.504 in the beginning period to 0.604 in the ending period, the magnitude of increase captures about 62% of that in the data. Figure 4 presents the trend of labor allocation between direct goods production and intangible capital investment activities within the two sectors. Over the time labor is shifted from producing sectoral goods to producing intangible capital in both sectors. And this shift is of a larger magnitude in sector 1, where intangible capital is always more important in the production function. The intuition is straightforward: when intangible capital investment becomes more productive, it pays to take advantage of the increased productivity and apply more labor to intangible capital investment, so that higher output level can be achieved in the future. And because intangible capital is more "useful" in sector 1, L_o increases more in that sector. In fact, the increase in sector 1's share of employment as a proportion of total labor force is primarily driven by the fact that more labor is allocated to intangible capital production, since the ratio of workers engaged in direct goods production between the two sectors–L_{y_1}/L_{y_2}– is constant. This channel of labor composition change is a major difference between the present paper and earlier structural change literature. It is also consistent with the stylized fact presented in Figure 2.

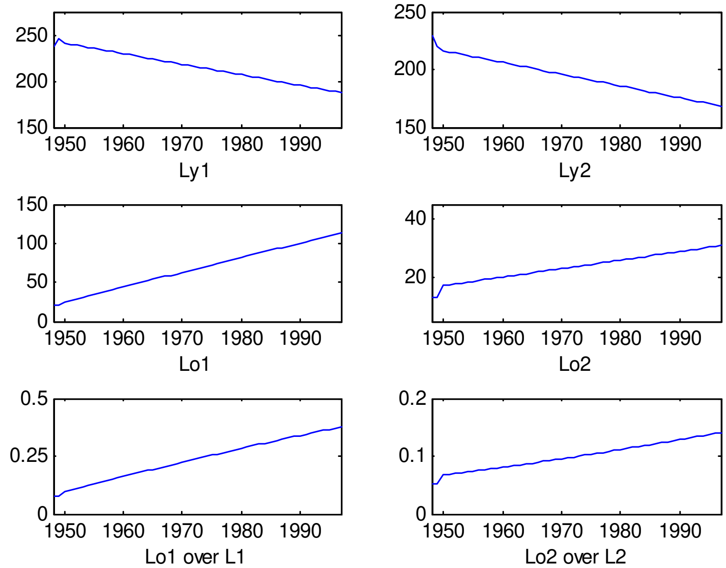

Figure 4

Next let's compare the labor productivity growth in the two sectors. The first row of table 3 lists the annual labor productivity growth– calculated as sectoral real output divided by total hours worked– in the data of the two sectors. There are several things worth noticing. First, for the earlier period (1949-1973), the high-intangible sector has a higher labor productivity growth than the low-intangible sector, while the opposite is true for the later period (1974-1997). Second, both sectors' productivity growth is lower in the second period than in the first period. Third, for the entire 50 year window, the productivity growth of the high-intangible capital sector is lower than the other sector.

All the three facts are captured in the model simulation, as shown in the second row of table 3. Here the labor productivity is calculated as $Y_i/\left(L_{y_i}+L_{o_i}\right)$. Though the productivity difference between the two sectors is milder in the model than in the data, the productivity time trend and direction of sectoral differences are the same. The fact that the intangible-capital intensive / growing sector has lower labor productivity growth than the low intangible capital sector seemingly confirms Baumol's hypothesis of the "cost disease of the service sector", which predicts that the expansion of the less productive sector will bring down the economic growth of the whole economy.

However, according to the present model, the ratio $Y_i/(L_{y_i}+L_{o_i})$, which is the counterpart of "labor productivity" in the data, is not the "true" labor productivity in sectoral goods production. Because in the labor force it includes L_{o_i}, which part of labor is not directly used in producing Y_i. The correct labor productivity in sectoral goods production should be the ratio Y_i/L_{y_i}. The third row of table 3 shows that the "true" labor productivity growth in the high intangible capital sector is actually always higher than the low-intangible sector, though the true labor productivity is very hard to calculate from the available data.

		Annual labor productivity growth (%)					
		High intangible sector			Low intangible sector		
		1949-1973	1974-1997	1949-1997	1949-1973	1974-1997	1949-1997
Data:	$Y_i / (L_{yi} + L_{oi})$	3.20	-0.94	1.17	2.49	0.72	1.62
Model:	$Y_i / (L_{yi} + L_{oi})$	2.31	0.20	1.28	2.19	0.39	1.31
Model:	Y_i / L_{yi}	3.03	0.91	1.99	2.39	0.41	1.42

Table 3: Labor productivity growth

According to Proposition 3, sectoral structural change related to intangible capital accumulation can be caused by either changes in intangible capital's shares in the sectoral production functions, which is experimented in the above simulation, or changes in intangible investment productivity. To examine the role of the latter, I ran a second calibration exercise. Unlike in the previous simulation, here b_1 and b_2 are kept constant, but the growth rate of intangible capital is assumed to be positive. I set b_i as the average of $b_{i,old}$ and $b_{i,new}$ in the baseline simulation: $b_1 = 0.235$; $b_2 = 0.108$. The value of g_B is calibrated so that the real output share increase in the intangible-capital intensive sector can match the magnitude in the data. This leads to an annual $g_B = 0.1$ after the initial period. The shares of the two sectors in the final goods production function are set as: $\gamma_1 = 0.53$, $\gamma_2 = 0.47$, so that the output and employment shares of the two sectors in the initial steady state match the data of year 1948. Other parameters are the same as in the baseline calibration.

Figure 5 displays the trends of sector 1's real output and employment shares. Both shares have increased over time, as in the previous simulation. But there is a crucial difference in the magnitude. Although a 10% annual investment productivity growth allows the changes in output shares to match the data, the change in labor shares, around 0.8%, is too small compared with the data, as shown in the second panel of figure 5. In fact, throughout all the simulation exercises I ran, no realistic level of employment structural change has been achieved by increasing g_B alone. In addition, the growth rate of "understated" labor productivity $Y_i/\left(L_{y_i} + L_{o_i}\right)$, is 0.0259 for the high-intangible sector, and 0.0159 for the low-intangible sector. This is contradictory to the empirical fact since, as mentioned in the baseline calibration, the labor productivity growth of the low-intangible sector is higher than that of the high-intangible sector in the data. Therefore, it seems that intangible investment-specific technology advance only plays a minor role in the structural change of employment allocation.

Figure 6 reports the result for within-sector labor allocation change. As in the previous simulation, labor is gradually shifted from goods production to intangible capital investment in both sectors. But again, the magnitude of the shift is much smaller than in the baseline calibration.

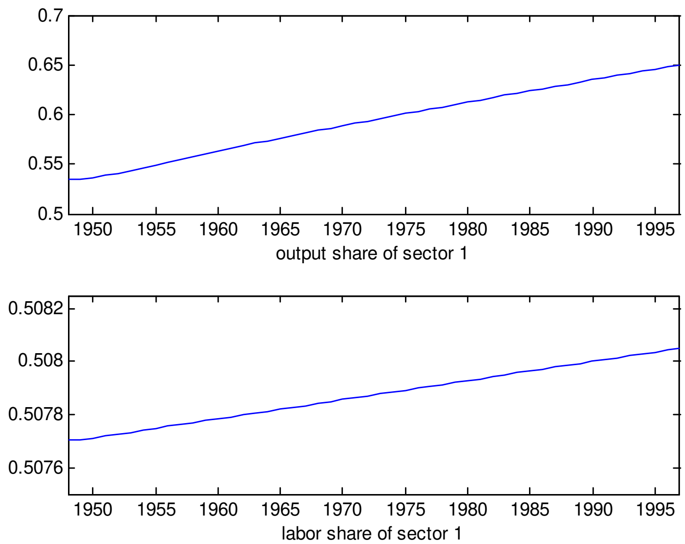

Figure 5

To sum up, this section ran calibration exercises on two mechanisms of intangible capital-induced sectoral structural change: (1) increasing shares of intangible capital in the production function; (2) increasing intangible investment productivity. For the first exercise, I calibrated changes of b_i through observed intangible investment over output ratio. The simulation is able to fully account for the output share growth of the intangible-intensive sector, and captures about 62% of the sector's employment share growth. It is interesting to note that the growth rate of the normal but understated labor productivity is lower in the expanding sector, as in the data. But the high intangible capital sector has a higher growth rate of the "true" labor productivity. In the second exercise, the growth rate of intangible investment specific technology is calibrated to match the output share increase of the high-intangible sector in the data. However, the g_B calibrated this way can only produce very limited change in labor shares.

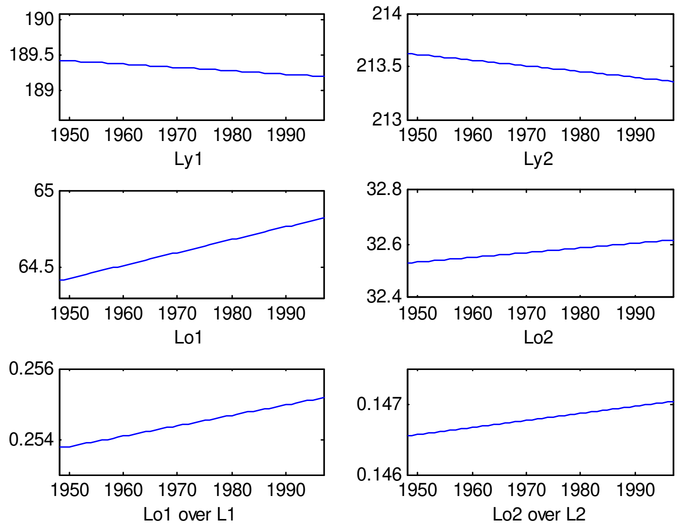

Figure 6

4.2 Sensitivity Analysis

Two parameters in the previous calibration exercises need closer examination, the coefficient of the decreasing return to scale in the investment goods production function d, and the depreciation rate of intangible capital φ. Both parameters are pre-assumed, have relatively few empirical support, and can influence the simulation result in a significant way. In this section, I apply alternative values to d and φ, and re-simulate model. In addition, the labor supply L_t was set to be constant in the baseline simulation. In this section, I will examine the case when $g_L > 0$.

Table 4 reports sector 1's output and employment share growth with different parameter values. Table 5 lists the values of annual productivity growth. Let's first look at the effect of changing the value of d. Column 2 and 3 of table 4 report the percentage change in sector 1's output and employment shares from 1948 to 1997 when $d = 0.9$ and when $d = 0.75$. When d is lower, that is, when the return to intangible investment goods production decreases faster with production scale, the high-intangible sector expands less. Besides, as shown in table 5, the labor productivity growth is also lower for both sectors when d is smaller. This result is quite intuitive. A lower d means that the payoff for allocating labor to intangible capital production is smaller. The equilibrium level of L_{o_i} and O_i are thus lower, and the structural effect of increasing b_i less pronounced. Since O_i accumulates slower with a lower d, the labor productivity growth is also lower.

	Data	d = 0.9	d = 0.75	φ = 0.35	φ = 0.65	g_L = 0.0178
Sector 1's output share growth (%)	8.70	7.34	6.56	7.55	6.30	7.21
Sector 1's employment share growth (%)	12.12	8.47	7.60	7.88	7.82	7.19

Table 4: Percentage change in sector 1's output & employment shares from 1948 to 1997

Next, I changed the intangible capital depreciation rate φ to 0.35 and 0.65. A lower φ generates more pronounced output share change and higher labor productivity growth, while its impact on labor share change is relatively limited. Finally, I changed the labor supply growth to 1.78% annually, which is equal to the average employment growth rate of US private sector between 1948 and 1997. The inclusion of a positive g_L decreases the magnitude of cross-sector labor allocation change, and not surprisingly, labor productivity growth decreases, too.

		Annual labor productivity growth (%)					
		High intangible sector			Low intangible sector		
		1949-1973	1974-1997	1949-1997	1949-1973	1974-1997	1949-1997
Data	$Y_i / (L_{yi} + L_{oi})$	3.20	-0.94	1.17	2.49	0.72	1.62
d = 0.9	$Y_i / (L_{yi} + L_{oi})$	2.46	0.26	1.38	2.34	0.45	1.42
	Y_i / L_{yi}	3.21	0.98	2.12	2.47	0.42	1.47
d = 0.75	$Y_i / (L_{yi} + L_{oi})$	2.22	0.18	1.22	2.12	0.36	1.26
	Y_i / L_{yi}	2.93	0.86	1.91	2.33	0.40	1.39
φ = 0.35	$Y_i / (L_{yi} + L_{oi})$	2.83	0.24	1.56	2.58	0.42	1.52
	Y_i / L_{yi}	3.56	0.94	2.27	2.77	0.44	1.63
φ = 0.65	$Y_i / (L_{yi} + L_{oi})$	1.93	0.19	1.07	1.92	0.37	1.16
	Y_i / L_{yi}	2.65	0.87	1.78	2.10	0.39	1.26
g_L = 0.0178	$Y_i / (L_{yi} + L_{oi})$	2.03	0.006	1.04	1.77	0.09	0.94
	Y_i / L_{yi}	2.89	0.50	1.72	1.88	0.27	1.09

Table 5

Notice in table 5 that in all the simulations, the productivity change has basically the same characteristics. The productivity growth is higher in the earlier half of the time window for both sectors. The high intangible capital sector has a higher productivity growth than the low intangible sector during the first half of the simulation, but a lower productivity growth in the second half. For the $\varphi = 0.35$ and $g_L = 0.0178$ scenarios, sector 1's productivity growth premium in the earlier period more than compensate for its slower productivity growth in the later period. So its average productivity growth for the whole time window turns out still higher than the low-intangible sector.

5 Empirical Analysis

5.1 Overview

In this section, I empirically test some major implications of the theoretical model presented in the previous section.

The first empirical exercise asks whether there is a positive relation between a firm's intangible investment productivity and its sales and employment, and whether such a relationship is stronger in the high-intangible-capital sector. Assuming that firms in the same sector share the same production characteristics except investment productivity, a firm's intangible capital investment is an increasing function of its investment productivity. Therefore, although intangible investment productivity is not directly observed, the intensity of intangible investment can be used as an indicator of firm's investment productivity level.

The second empirical exercise takes the more aggregate level observation to detailed industry level, and asks whether there is a positive linkage between industries' intangible capital intensity and their output and employment growth. The exercise can be seen as an industry-level test of the model prediction. The regression analysis also compared the impact of intangible capital on industry growth with the impact of other factors that can potentially affect the structural change process.

5.2 Data

Data availability is a common obstacle for intangible capital research, as companies generally do not directly recognize intangible capital on their balance sheets. However, many cost items in building intangible capital are expensed in firms' Sales, General & Administrative expenditure (SG&A), including R&D cost, marketing expenses, management fees, software expenditures, etc. SG&A has been used as approximation for firms' intangible investment in recent empirical accounting literature. (See, Lev & Radhakrishnan (2005), Banker, Huang & Natarajan (2006), for example.) Following this literature, I use SG&A expenditure to approximate intangible investment in the empirical regressions. Since this is not a precise measure of firms' intangible investment, the related regression estimates should be seen as only suggestive to the direction and magnitude of the "true" coefficients. Four data sources are used in this paper: (1) COMPUSTAT North America database, from where I obtained publicly-traded firms' financial statement information, including SG&A expenditure, number of employment, annual sales, total assets, fixed assets data, and firms' SIC industry classification. (2) BEA annual industry accounts data, which includes information about industries' real and nominal value-added by SIC two-digit industries. (3) BLS data of capital income and IT investment by industry. (4) Education level data of industry labor force from Current Population Survey. The data periods are from 1950 to 1997. The key variables are summarized in Table 6, which provides means, standard deviations and ranges for each variable.

Variable	Mean	Std	Min	Max
	Firm level data			
Sales ($mn)	1035.796	6331.785	0.0040	375376
Employment (thousand)	7.603	30.751	0.0010	2100
SG&A ($mn)	186.559	1078.610	0.0010	70297
Property, plant & equipments ($mn)	711.271	5257.124	0.0010	373906.3
Total assets ($mn)	1088.135	7745.468	0.0010	795337
SG&A/Sales	0.256	0.182	0.0000	10
SG&A/Total assets	0.338	0.521	0.0000	176.3658
Sales/Total assets	1.459	1.351	0.0025	279.1219
Employment/Total assets	0.028	0.179	0.0000	30.1782
Sales growth rate	0.133	0.389	-5.6142	9.6194
	Industry level data			
Real output share	0.018	0.025	0.0003	0.1577
Employment share	0.019	0.027	0.0003	0.2034
Capital income/Output	0.394	0.191	0.0037	0.9626
Industry median SG&A/Sales	0.184	0.086	0.0017	0.6936
College-educated worker share	0.349	0.185	0.0139	0.8776
IT investment/Output	0.001	0.003	0.0000	0.0403
Growth rate of output share	-0.002	0.134	-2.3873	2.1577
Growth rate of employment share	-0.004	0.051	-0.9169	0.4618

Table 6: Summary statistics

5.3 Empirical Model

5.3.1 Firm Level Model

As in the multiple-firm section of the theoretical model, I assume that the intangible investment productivity differs across firms. According to the theory, the firms with higher intangible productivity shocks have higher output/employment growth. And since intangible investment is increasing in a firm's investment productivity, we shall observe a positive relationship between firm's SG&A investment intensity and its next period output/employment growth. Furthermore, the model predicts that the positive correlation between intangible investment productivity and a firm's output/employment is higher in the intangible capital intensive sector, i.e., the sector with a higher b_i. To test these hypotheses, I estimate the following empirical regression:

$$\begin{aligned} g_{y_{ij},t} &= \beta_0 + \beta_1 \left(\frac{SG\&A}{Y}\right)_{ij,t-1} + \beta_2 \left(\frac{SG\&A}{Y}\right)_{ij,t-1} \times \text{growsec} + \beta_3 \left(\frac{I_k}{Y}\right)_{ij,t-1} \\ &\quad + \beta_4 \left(\frac{I_i}{Y}\right)_{ij,t-1} \times \text{growsec} + \beta_5 \text{growsec} + \beta_6 control_{ij,t-1} + u_{ij,t} \end{aligned} \tag{14}$$

where $g_{y_{ij},t}$ is the sales growth rate of firm i in industry j; $\frac{SG\&A}{Y}$ is the ratio of sg&a expenditure over sales, which indicates a firm's intangible investment intensity, thus its investment productivity level; $\frac{I_k}{Y}$ is the ratio of physical capital investment over sales; "growsec" is a dummy variable, which equals 1 if the firm belongs to the growing sector that is also more intangible capital intensive. $control$ is a vector of control variables, which includes firms's total assets and physical capital. I assume that the error term contains time and industry fixed effects:

$$u_{ij,t} = \mu_j + \varepsilon_t + v_{ij,t}$$

where $v_{ij,t}$ is assumed to be i.i.d. across firms with mean 0 and variance σ_v^2.

The interaction term between intangible investment intensity and sector categorization is meant to capture the difference in the correlation between intangible investment and output across sectors. For the growing sector, which is generally more intangible capital intensive, the correlation between intangible investment and output growth in the regression equation is equal to $\beta_1 + \beta_2$, while for the declining sector, it is equal to β_1. According to Proposition 4, we shall expect both β_1 and β_2 to be positive.

To make sure that the coefficient for SG&A is not a stand-in for the impact of other investments, I also include physical capital investment and its interaction with growing sector dummy in the regression specification. Moreover, the interaction term allows us to compare the effects of the two types of investment across sectors.

A similar regression model can be applied to the relationship between firm's employment growth and its intangible investment productivity. The estimation equation is

$$\begin{aligned} g_{l_{ij},t} &= \gamma_0 + \gamma_1 \left(\frac{SG\&A}{Y}\right)_{ij,t-1} + \gamma_2 \left(\frac{SG\&A}{Y}\right)_{ij,t-1} \times \text{growsec} + \gamma_3 \left(\frac{I_k}{Y}\right)_{ij,t-1} \\ &\quad + \gamma_4 \left(\frac{I_i}{Y}\right)_{ij,t-1} \times \text{growsec} + \gamma_5 \text{growsec} + \gamma_6 control_{ij,t-1} + \omega_{ij,t} \end{aligned} \tag{15}$$

where $g_{l_{ij},t}$ =growth rate of employment in firm i of industry j. Again, according to the theory, both γ_1 and γ_2 should be positive.[7]

5.3.2 Industry Level Model

The theoretical model suggests that the a sector's real output and employment are increasing in intangible capital's share in the production function b_i. And the sector with higher b_i grows more with an increase in g_B. At an industry-level regression setting, both predictions imply a positive relationship between industry i's share growth and its intangible capital intensity, b_i. The calibration section shows that the relative level of b_i can be inferred

[7] Models that relate output to capital investment generally raise simultaneity concerns. If the company correctly forsees that in the future period, there will be a positive exogenous shock other than the intangible investment productivity, say, a shock from the demand side, the company will increase its capital investment in the present period, and in the future period when the shock is realized, the sales are higher partly due to the shock. In that case, the estimated coefficient for the investment variable will be inconsistent. And this is true for both tangible and intangible investment. But will it seriously undermine the regression results in the present setting? My answer is no. The reason is that the main purpose of this empirical exercise is not to precisely estimate the impact of investment on future output, but rather to see whether the direction of the estimates is as predicted by the theory, more specifically, to confirm whether the coefficients of intangible investment and its interaction with growing sector dummy have a positive sign. I argue that the bias caused by endogeneity issue will most likely work against this goal, thus it won't deminish the robustness of the results. The reason is the following. If the exogenous shocks the firms receive are negative, it will downward bias the coefficients for SG&A investment. If the shocks are positive, it can inflate the coefficient for $\frac{SG\&A}{Y}$, but will downward bias the coefficient for the interaction term between $\frac{SG\&A}{Y}$ and growing sector dummy, assuming the distribution of shocks is the same across sectors. And this is because that for the same exogenous shock, the firms in the growing/intangible capital intensitve sector will choose to raise SG&A investment more than the firms in the other sector, as intangible capital is an input more important in the growing sector. In other words, the coefficient for the interaction term will most likely to be underestimated because of endogeneity.

from the relative level of intangible capital investment across sectors. Therefore, to test the relationship between industry growth and its intangible capital intensity, I regress the growth rate of industry's output/employment shares on its lagged intangible capital investment index. It is assumed that a higher SG&A index corresponds to a higher b.

In the model, I assume that the share of intangible capital in the production function for each sector is fixed over time, i.e. $b_{it} = b_i$ for $0 \leq t \leq \infty$. In reality, industries' production characteristics may gradually change over time. If, as predicted by the model, there is a positive relationship between industry's b and its share growth, the relationship should hold not only across industries, but also throughout time for any specific industry. Therefore, I estimated a panel regression model over a panel of 51 SIC 2-digit industries. The regression specifications are as follows:

$$g\_yshare_{j,t-s,t} = \chi_0 + \chi_1 g\_yshare_{j,t-1-s,t-1} + \chi_2 INDEX\_SGA_{j,t-s} \\ +\chi_3 INDEX\_K_{j,t-s} + \chi_4 INDEX\_EDU_{j,t-s} + \chi_5 INDEX\_IT_{j,t-s} + \upsilon_{j,t} \tag{16}$$

$$g\_lshare_{j,t-s,t} = \lambda_0 + \lambda_1 g\_lshare_{j,t-1-s,t-1} + \lambda_2 INDEX\_SGA_{j,t-s} \\ +\lambda_3 INDEX\_K_{j,t-s} + \lambda_4 INDEX\_EDU_{j,t-s} + \lambda_5 INDEX\_IT_{j,t-s} + \eta_{j,t} \tag{17}$$

$g\_yshare_{j,t-s,t}$ is the average growth of industry j's share of output in total private sector output from t-s to t;

$g\_lshare_{j,t-s,t}$ is the average growth of industry j's share of employment in total private sector employment from t-s to t;

SGA_j is the median level SG&A expenditure/sales ratio in industry j;

To control for the presence of other factors that might also contribute to the sectoral structural change, I include, in the explanatory variables, industry's human capital and physical capital intensities and information technology investment intensity. These factors are taken from related literature on sectoral structural change and productivity growth, as outlined in the literature review section. They include:

K_j: the physical capital intensity of industry j, calculated as capital income over value-added of the industry;

EDU_j: the human capital intensity of industry j, calculated as the number of workers who received at least some college education over the total industry workforce;

IT_j: the intensity of information technology investment in industry j, represented by the ratio of the amount of industry IT investment to industry value-added.

All explanatory variables are in the relative-value form– they are divided by the cross-industry mean of the year. In other words, the right-hand-side variables are in the form: $INDEX\_X_{j,t} = X_{j,t}/\overline{X}_t$. Given the fact that structural change is a long-term process and changes in intangible capital intensity might not be immediately reflected in industries' output/employment shares, I choose a base-line time lag $s = 5$ years when executing the regressions. In the result section, estimates with $s = 3$ and $s = 10$ are also reported. Since the dependent variables are s-year average industry share growth, there are overlaps between the values of adjacent time periods. To allow for this slow adjustment, I include a lagged dependent variable on the right hand side. This implies a correlation between the regressors and the error term, since the lagged dependent variable depends on the error term in t-1, which includes an industry fix effect factor. To correct for the potential bias, I use the dynamic GMM method developed by Arellano and Bond (1991) to estimate the model. Their procedure also eliminates endogeneity that may be caused by any correlation between industry specific factor and other right-hand-side variables.

5.4 Estimation Results and Analysis

Table 7a and 7b present the results for the firm-level regressions– equation 14 and 15. Both OLS and panel regression coefficients are reported. Table 8 presents the results of industry-level regressions– equation 16 and 17, where the growth of industry output/employment shares is regressed on lagged factor intensity in intangible capital, human capital, IT and physical capital.

Let's first look at the results of firm-level regressions. In Table 7a, the SG&A intensity variable's coefficients are positive and significant at 1% level in all variations of the regression specification, which is consistent with the hypothesized relationship between firm's intangible investment productivity and output. Quantitatively, the coefficients– both around 0.15– do not differ much between OLS and fixed effect models. On average, the variation in SG&A expenditure explains about 10% of the variation in sales growth.

The magnitude of intangible investment's correlation with sales is not the same across the expanding and declining sectors– the coefficients for the interaction term between growing-sector dummy and SG&A intensity are positive and significant at 1% level. In other words, for the firms that belong to the expanding sector, which is in general also more intangible capital intensive, intangible investment has a higher correlation with firms' output growth, which is predicted by the theoretical model. Quantitatively, the correlation is 30% higher in the growing sector than in the declining sector. As a comparison, let's look at the coefficients for physical capital investment. Quite intuitively, the coefficient for I_k/y is positive. But the coefficient for the interaction term between physical investment and growing sector dummy is negative and significant, indicating that, unlike intangible capital, physical capital is not more productive in the growing sector. It is also interesting to note that the coefficients for log(fixed assets) are negative across all regressions, which indicates that firms which are more "tangible" grow less.

	Growth rate of sales $_t$			
	model1	model2	model3	model4
$(sg\&a/y)_{t-1}$	0.154***	0.157***	0.115***	0.117***
	(94.6)	(93.52)	(26.05)	(26.26)
$(I_K/y)_{t-1}$	0.005***	0.005***	0.041***	0.040***
	(40.34)	(40.65)	(33.95)	(33.65)
$(sg\&a/y)\times growsec_{t-1}$			0.036***	0.038***
			(7.69)	(8.00)
$(I_K/y)\times growsec_{t-1}$			-0.036***	-0.036***
			(-29.94)	(-29.65)
growsec			0.001	-0.279***
			(0.28)	(-4.59)
log(total assets)$_{t-1}$	0.001	0.006***	0.003**	0.007***
	(1.15)	(4.43)	(2.84)	(5.04)
log(fixed assets)$_{t-1}$	-0.008***	-0.013***	-0.010***	-0.014***
	(-7.99)	(-11.1)	(-9.92)	(-11.96)
	pooled ols	time & industry fix effect	pooled ols	time & industry fix effect
r2	0.063	0.084	0.067	0.088
N	193554	193340	193554	193340

Table 7a: Impact of Intangible capital investment on firm sales growth

The results in Table 7b show that when the two sectors are pooled together, intangible investment productivity is positively correlated with firms' employment growth– the coefficients of SG&A intensity are positive for both OLS and fixed effect regressions, and are significant at 1% and 5% level respectively. However, when adding the interaction term between sg&a intensity and the growing sector dummy, it becomes clear that the positive sign for the coefficients of intangible capital investment in the pooled regressions is driven mainly by the firms in the growing sector. When the two sectors are treated separately, the coefficients for SG&A intensity are slightly negative and insignificant for the declining sector, while the same variable's coefficients are positive and significant at 1% level, for the expanding sector. The result indicates that intangible capital investment is associated with higher employment growth only for the growing sector, which is in line with the theoretical model's prediction. It is also interesting to see that the effect of physical capital investment on employment is the exact opposite for the two sectors– the coefficients are higher for the declining sector than for the growing sector. The contrast between the coefficients of intangible capital investment and of physical capital investment further supports the paper's proposition that intangible capital plays a unique role in the structural change and growth process. In addition, the coefficients for fixed assets have a negative sign, which shows that firms with more tangible capitals generally have lower employment growth.

	Growth rate of employment $_t$			
	model1	model2	model3	model4
$(sg\&a/y)_{t-1}$	0.019***	0.013***	-0.002	-0.008
	(9.36)	(6.11)	(-0.34)	(-1.6)
$(I_K/y)_{t-1}$	0.0002	0.0002*	0.004***	0.005***
	(1.87)	(2.00)	(3.42)	(3.60)
$(sg\&a/y) \times growsec_{t-1}$			0.024***	0.024***
			(4.37)	(4.36)
$(I_K/y) \times growsec_{t-1}$			-0.004***	-0.004***
			(-3.26)	(-3.43)
growsec			0.015***	0.002
			(5.73)	(0.00)
log(total assets)$_{t-1}$	0.027***	0.026***	0.027***	0.026***
	(19.74)	(17.12)	(19.58)	(17.06)
log(fixed assets)$_{t-1}$	-0.029***	-0.032***	-0.029***	-0.032***
	(-25.08)	(-23.93)	(-24.98)	(-23.92)
	pooled ols	time & industry fix effect	pooled ols	time & industry fix effect
r2	0.008	0.026	0.008	0.026
N	174252	174210	174252	174210

Table 7b: Impact of Intangible capital investment on firm employment

Table 8 presents the results of industry level regressions. In the output share growth regression, the coefficients for lagged SG&A intensity are all positive and significant above 5% level, indicating strong positive correlation between intangible capital intensity and future industry growth. In the employment share growth regressions, the coefficients for intangible investment are also positive, and only insignificant for the 10-year window, though the coefficients are an order smaller than those in the output share regression. It is also interesting to note that the lagged IT investment intensity has mostly positive and significant correlation with industry output share growth. This result lends support to the argument advocating ICT as a general purpose technology and an important source of productivity growth. In contrast, lagged human capital and physical capital intensities, which were identified in some structural change literature as causing factors for sectoral composition change, do not show significant correlation with industry share growth, except for the 10-year-lag coefficient of physical capital intensity in the employment regression, which is negative and significant at 1% level.

	Output share growth			Employment share growth		
	3 year window	5 year window	10 year window	3 year window	5 year window	10 year window
lagged dependent variable	0.584***	0.695***	0.743***	0.721***	0.813***	0.901***
	(32.01)	(41.3)	(46.32)	(47.19)	(59.04)	(73.05)
lagged Intangible capital investment intensity	0.023**	0.020***	0.017***	0.006**	0.006***	0.002
	(2.71)	(3.67)	(4.9)	(2.86)	(3.6)	(1.67)
lagged human capital intensity	-0.009	-0.013	-0.004	0.0009	0.003	0.001
	(-0.89)	(-1.94)	(-1.01)	(0.35)	(1.63)	(1.23)
lagged IT investment intensity	0.006***	0.004***	0.003***	0.0004**	0.00005	-0.0001*
	(11.28)	(11.71)	(14.15)	(2.58)	(0.49)	(-2.13)
lagged physical capital intensity	-0.001	0.0002	-0.003	-0.002	0.002	-0.003***
	(-0.11)	(0.04)	(-1.03)	(-0.63)	(1.09)	(-3.49)
constant	-0.031*	-0.020	-0.019**	-0.010**	-0.014***	-0.00009
	(-1.93)	(-1.8)	(-2.96)	(-2.19)	(-4.23)	(-0.05)
N	1480	1376	1116	1480	1376	1116

Table 8: Impact of Intangible capital investment on industry output & employment share growth

Overall, the empirical findings in this section strongly support the following implications of the theoretical model. At firm level, higher intangible capital investment– indicating a higher level of intangible investment productivity– is associated with higher output and employment growth. This correlation is stronger in the intangible-capital-intensive sector. At industry level, there is a strong positive correlation between an industry's intangible capital intensity and industry's output/employment share growth.

6 Robustness Check

A disadvantage of using growth rate as dependent variable is that it can be susceptible to firm size and age biases. Specifically, it is possible that small and young firms which have higher SG&A to sales ratio also tend to grow faster than old firms, which may induce an upward bias in the coefficients when growth rate is regressed on SG&A intensity. Therefore, as a robustness check, I also estimate a second specification, which directly regresses the level of firm sales on its lagged SG&A spending:

$$\begin{aligned}\left(\frac{Y}{A}\right)_{ij,t} = {} & \alpha_0 + \alpha_1\left(\frac{SG\&A}{A}\right)_{ij,t} + \alpha_2\left(\frac{SG\&A}{A}\right)_{ij,t-1} + \alpha_3\left(\frac{SG\&A}{A}\right)_{ij,t} \times \text{growsec} \\ & +\alpha_4\left(\frac{SG\&A}{A}\right)_{ij,t-1} \times \text{growsec} + \alpha_5\left(\frac{I_k}{A}\right)_{ij,t} + \alpha_6\left(\frac{I_k}{A}\right)_{ij,t-1} \\ & +\alpha_7\left(\frac{I_k}{A}\right)_{ij,t} \times \text{growsec} + \alpha_8\left(\frac{I_k}{A}\right)_{ij,t-1} \times \text{growsec} + \alpha_9\text{growsec} + \alpha_{10}control_{ij,t} + e_{ij,t}\end{aligned} \quad (18)$$

where Y_{ij} =sales of firm i in industry j. All variables are scaled by firm's total asset, A, to mitigate possible heteroscedasticity problem. The control variable in this equation is firms' physical capitals scaled by total assets. Because investments are likely to be serially correlated, I include current period SG&A and physical capital investment in the regression equation, to make sure that the coefficients for lagged investment variables are not biased because of their correlation with the current period investments.

The counterpart regression on the employment side is

$$\begin{aligned}\left(\frac{L}{A}\right)_{ij,t} &= \lambda_0 + \lambda_1 \left(\frac{SG\&A}{A}\right)_{ij,t} + \lambda_2 \left(\frac{SG\&A}{A}\right)_{ij,t-1} + \lambda_3 \left(\frac{SG\&A}{A}\right)_{ij,t} \times \text{growsec} \\ &+\lambda_4 \left(\frac{SG\&A}{A}\right)_{ij,t-1} \times \text{growsec} + \lambda_5 \left(\frac{I_k}{A}\right)_{ij,t} + \lambda_6 \left(\frac{I_k}{A}\right)_{ij,t-1} \\ &+\lambda_7 \left(\frac{I_k}{A}\right)_{ij,t} \times \text{growsec} + \lambda_8 \left(\frac{I_k}{A}\right)_{ij,t-1} \times \text{growsec} + \lambda_9 \text{growsec} + \lambda_{10} control_{ij,t} + e_{ij,t}\end{aligned} \tag{19}$$

where L_{ij} =employment of firm i in industry j. According to the hypotheses, we shall expect $\alpha_1, \alpha_2, \lambda_1, \lambda_2$ to all be positive.

The results in Table 9a and 9b, using the alternative specification, reflect a similar pattern as in previous firm-level regressions. The intangible investment has a positive correlation with future outputs when the two sectors are pooled together. But when they are separated, the correlation is only positive and significant for the expanding sector. One thing surprising is that the coefficient for lagged physical capital investment is positive only for the declining sector using fixed effect regression, and is otherwise negative. On the employment side, higher intangible capital investment is associated with larger employment size only for firms in the expanding sector, while for the declining sector, the coefficients are negative and not significant. It is also worth noticing that the physical capital's association with sales are mostly negative, especially for the growing sector. Its relationship with employment is mixed.

	Sales/t.a $_t$			
	model1	model2	model3	model4
$(sg\&a/t.a.)_t$	0.188*** (157.26)	0.188*** (161.28)	0.629*** (129.83)	0.567*** (113.98)
$(sg\&a/t.a.)_{t-1}$	0.354*** (181.56)	0.323*** (163.86)	-0.003 (-1.31)	-0.003 (-1.51)
$(I_K/t.a.)_t$	0.064*** (7.45)	0.068*** (8.03)	-0.039** (-2.69)	0.040** (2.75)
$(I_K/t.a.)_{t-1}$	-0.089*** (-10.61)	-0.070*** (-8.47)	-0.024 (-1.78)	0.040** (2.95)
$(sg\&a/t.a.) \times growsec_t$			-0.262*** (-51.46)	-0.209*** (-40.16)
$(sg\&a/t.a.) \times growsec_{t-1}$			0.022*** (8.37)	0.017*** (6.48)
$(I_K/t.a.) \times growsec_t$			0.037* (2.1)	-0.088*** (-4.94)
$(I_K/t.a.) \times growsec_{t-1}$			-0.002 (-0.14)	-0.117*** (-6.92)
growsec			0.091*** (32.28)	0.056 (1.47)
	pooled ols	time & industry fix effect	pooled ols	time & industry fix effect
r2	0.97	0.97	0.94	0.94
N	157222	157222	191941	191728

Table 9a: Impact of Intangible capital investment on firm sales

	Employment/t.a $_t$			
	model1	model2	model3	model4
$(sg\&a/t.a.)_t$	-0.004*** (-11.58)	-0.003*** (-8.94)	0.016*** (7.65)	0.015*** (6.96)
$(sg\&a/t.a.)_{t-1}$	0.003*** (7.83)	0.003*** (6.83)	-0.0003 (-0.34)	-0.00001 (-0.01)
$(I_K/t.a.)_t$	0.012** (3.12)	0.002 (0.56)	-0.009 (-1.34)	0.0002 (0.04)
$(I_K/t.a.)_{t-1}$	0.002 (0.58)	-0.005 (-1.33)	-0.011 (-1.69)	-0.001 (-0.15)
$(sg\&a/t.a.) \times growsec_t$			-0.021*** (-9.8)	-0.019*** (-8.62)
$(sg\&a/t.a.) \times growsec_{t-1}$			0.003** (3.14)	0.003** (2.75)
$(I_K/t.a.) \times growsec_t$			0.034*** (4.26)	0.002 (0.27)
$(I_K/t.a.) \times growsec_{t-1}$			0.021** (2.75)	-0.006 (-0.8)
growsec			-0.0008 (-0.63)	-0.006 (0.00)
	pooled ols	time & industry fix effect	pooled ols	time & industry fix effect
r2	0.016218	0.05828	0.017577	0.059108
N	181247	181118	181247	181118

Table 9b: Impact of Intangible capital investment on firm employment

7 Intangible Capital Investment and the Rise of Service Sector

The conventional sector classification divide industries– according to the nature of their output– into goods-producing and service-producing sectors. It is a well-known fact that during the past several decades, the service sector has grown disproportionately relative to the goods-producing sector in both real output and employment, as shown in Figure 7.

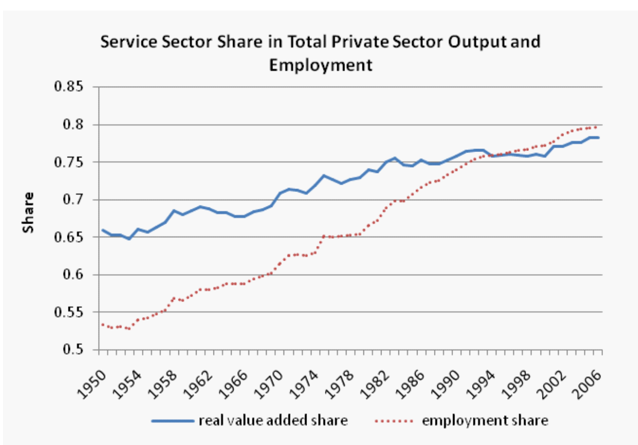

Figure 7: Service Sector Share of Real Output and Employment

The phenomenon can be readily explained by examining the intangible capital intensity of service industries. First of all, if we look at data more closely, it is easy to see that contrary to the popular perception, not all service industries are expanding. Table 10a and 10b list respectively the service industries whose real value added shares have increased and decreased over the period 1977-2007, based on NAICS classification.

Further examining the growing service industries, we can see that this part of the service sector is mostly intangible capital intensive. As before, I divide industries into high and low intangible capital group according to whether their average SG&A to sales ratio is above the median across industries. Table 10a and 10b list the intangible capital intensity of each service industry during the period and whether the industry belongs to the high or low intangible capital group. Figure 8 plots the real value added share growth of all service industries from 1977 to 2007 against their intangible capital intensities.

High Intangible and Growing Service Industries				
NAICS	Industry	Intangible Capital Intensity	Real Value Added Share	
			2007	1977
42	Wholesale trade	0.1695	0.0673	0.0466
44,45	Retail trade	0.2497	0.0895	0.0596
493	Warehousing and storage	0.1896	0.0033	0.0018
511	Publishing industries (includes software)	0.4924	0.0139	0.0086
512	Motion picture and sound recording industries	0.2076	0.0036	0.0033
513	Broadcasting and telecommunications	0.2454	0.0396	0.0167
514	Information and data processing services	0.2223	0.0085	0.0021
523	Securities, commodity contracts, and investments	0.3781	0.0281	0.0014
5412-5414,5416-5419	Miscellaneous professional, scientific, and technical services	0.2301	0.0576	0.0280
5415	Computer systems design and related services	0.3517	0.0168	0.0032
561	Administrative and support services	0.2002	0.0293	0.0148
621	Ambulatory health care services	0.2173	0.0408	0.0406
		Total share:	0.3982	0.2267
Low Intangible and Growing Service Industries				
NAICS	Industry Name	Intangible Capital Intensity	Real Value Added Share	
			2007	1977
481	Air transportation	0.0986	0.0087	0.0027
484	Truck transportation	0.0475	0.0102	0.0098
532,533	Rental and leasing services and lessors of intangible assets	0.1528	0.0109	0.0084
624	Social assistance	0.1096	0.0076	0.0034
711712	Performing arts, spectator sports, museums, and related activities	0.1174	0.0045	0.0032
713	Amusements, gambling, and recreation industries	0.1561	0.0058	0.0046
722	Food services and drinking places	0.0983	0.0197	0.0188
		Total share:	0.0674	0.0509

Table 10a: IC Intensity of Growing Service Industries (1977-2007)

High Intangible and Declining Service Industries				
NAICS	Industry Name	Intangible Capital Intensity	Real Value Added Share	
			2007	1977
521,522	Federal Reserve banks, credit intermediation, and related activities	0.2177	0.0398	0.0506
5411	Legal services	0.2601	0.0131	0.0199
562	Waste management and remediation services	0.1711	0.0026	0.0030
61	Educational services	0.3625	0.0087	0.0107
81	Other services, except government	0.2567	0.0227	0.0382
		Total share:	0.0868	0.1225
Low Intangible and Declining Service Industries				
NAICS	Industry Name	Intangible Capital Intensity	Real Value Added Share	
			2007	1977
22	Utilities	0.0656	0.0197	0.0265
482	Rail transportation	0.0613	0.0028	0.0037
483	Water transportation	0.0864	0.0008	0.0008
485	Transit and ground passenger transportation	0.1096	0.0015	0.0036
486	Pipeline transportation	0.0474	0.0011	0.0016
487,488, 492	Other transportation and support activities	0.1139	0.0074	0.0074
524	Insurance carriers and related activities	0.1261	0.0245	0.0336
525	Funds, trusts, and other financial vehicles	0.0117	0.0011	0.0032
531	Real estate	0.0205	0.1253	0.1356
622,623	Hospitals and nursing and residential care facilities	0.0885	0.0256	0.0377
721	Accommodation	0.1516	0.0092	0.0139
		Total share:	0.2189	0.2677

Table 10b: IC Intensity of Declining Service Industries (1977-2007)

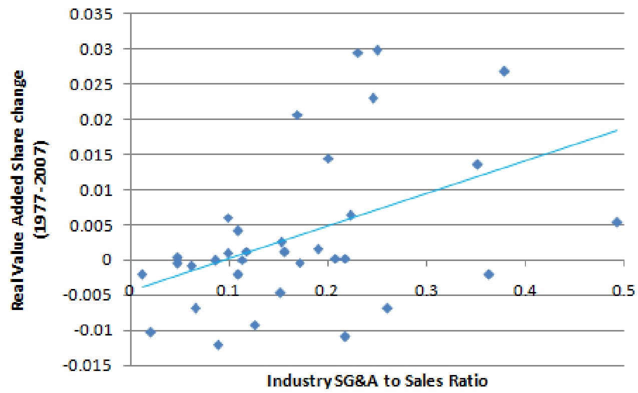

Figure 8: Service Inudustries' Growth and Intangible Capital Intensity

As shown in the tables, the intangible capital intensive industries are quantitatively important in explaining the expansion of the service sector. The growing part of the service sector is dominated by intangible capital intensive industries. In 2007, the high-intangible-capital industries, such as 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 low on intangible capital, such as utilities, water/ rail/ pipeline transportations and real estate services. These low intangible capital industries constitute 72% of the declining service sector's total value-added share in 2007.

8 Conclusion

This paper provided an explanation to the sectoral structural change in US economy during the recent decades. It argues that as the economy shifts towards more reliance on knowledge and information in the production process, the differences in intangible capital accumulation across sectors leads to structural changes in both output and employment compositions. In the two-sector model of the paper, the importance of intangible capital in the production function differs across sectors and increases overtime. There are two kinds of work tasks in the model economy: directly producing sectoral goods and creating intangible capital investment for future production. When intangible capital's share in the production function rises or the productivity of intangible investment increases, both sectors invest more in intangible capital, and the output and employment of the high intangible sector grows faster than that of the low intangible sector.

The implications of the model are consistent with the stylized facts about structural change and intangible capital accumulation in the US economy since the 1950s. With reasonable choice of parameters, the model can generate output and employment composition changes that quantitatively match the empirical data from 1950 to late 1990s. The labor productivity trends generated by the model are also in line with empirical data. In addition, the model implies that the labor productivity calucated as output over total labor input underestimates the real productivity in goods and service production, as part of the labor force is engaged in intangible investment instead of direct production. This underestimation is more severe for the growing high intangible sector.

Empirical estimations reveal that firms' intangible capital investment, approximated by firms' SG&A spending intensity, has significant and positive correlations with future output and employment growth. The correlations are higher in the growing (more intangible capital intensive) sector. The industry-level regressions show that after controlling for other factors,– industry human capital and physical capital Intensity and IT investment intensity– the index of industry SG&A spending is positively correlated with industry share growth in both real output and employment. These results are consistent with the model's predictions.

Evidence suggests that growing service industries are mostly intangible capital intensive. Thus the theory developed in this paper can in particular help to reconcile the expansion of the service industries and the seemingly low productivity growth of that sector.

A Appendix

A.1 Solving the Planner's Problem

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

First order conditions for the planner's problem:

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

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

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

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

$$L_{o_{it}}: \quad \eta_t = \phi_{it}B_{it}dL_{o_i,t}^{d-1} \tag{24}$$

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

$$\Longrightarrow \quad \lambda_t I_t = \beta\lambda_{t+1}\left[(1-\delta)\,I_{t+1}+\delta\gamma_i a_i Y_{t+1}\frac{K_{t+1}}{K_{i,t+1}}\right]$$

$$O_{i,t+1}: \ \phi_{it} = \beta \left[\mu_{i,t+1} b_i \frac{Y_{i,t+1}}{O_{i,t+1}} + (1-\varphi)\, \phi_{i,t+1} \right] \tag{26}$$

Let $S_c = C_t/Y_t$, equation 22, 25, and 21 $\Longrightarrow$

$$\begin{aligned} (1 - S_c) &= \beta (1-\delta)(1-S_c) + \beta\delta (\gamma_1 a_1 + \gamma_2 a_2) \\ \Longrightarrow &\quad S_c = 1 - \frac{\beta\delta(\gamma_1 a_1 + \gamma_2 a_2)}{1 - \beta(1-\delta)} \end{aligned}$$

Equation 23, 24, 26, and 21 $\Longrightarrow$

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

A.2 Other Results

A.2.1 Proof of Proposition 2

The wage rate w_t is equal to the marginal productivity of labor in each sector. Therefore the intangible investment cost to output ratio can be written as

$$\frac{w_t L_{o_i,t}}{P_{i,t} Y_{i,t}} = \frac{MPL_{i,t} P_{i,t} L_{o_i,t}}{P_{i,t} Y_{i,t}} = (1 - a_i - b_i) \frac{L_{o_i,t}}{L_{y_i,t}}$$

Plugging equation 4 into the above equation, we arrive at the steady state investment to output ratio

$$\frac{w L_{o_i}}{p_i Y_i} = \frac{\beta d (g_{B_i} + \varphi)}{1 + g_{B_i} - \beta + \beta\varphi} b_i$$

It is easy to see that $\frac{\partial}{\partial b_i}\left(\frac{wL_{o_i}}{p_i Y_i}\right) > 0$ and $\frac{\partial}{\partial g_{B_i}}\left(\frac{wL_{o_i}}{p_i Y_i}\right) > 0$.

A.2.2 Proof of Proposition 3

Combing equation 4 and 2, we can write the steady-state labor ratio between the two sectors as

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

It is straightforward to see that $\frac{\partial}{\partial g_{B_1}}\left(\frac{L_1}{L_2}\right) > 0$ and $\frac{\partial}{\partial g_{B_2}}\left(\frac{L_1}{L_2}\right) < 0$. $\frac{L_1}{L_2}$ is also increasing with b_1, if the increase in b_1 is offset by a decrease in a_1, $\Delta b_1 = -\Delta a_1$. If $g_{B_1} = g_{B_2} = g_B$, we have

$$\frac{L_1}{L_2} = \frac{\gamma_1 \beta b_1 d (g_B + \varphi) + \gamma_1 (1 - a_1 - b_1)(1 + g_B - \beta + \beta\varphi)}{\gamma_2 \beta b_2 d (g_B + \varphi) + \gamma_2 (1 - a_2 - b_2)(1 + g_B - \beta + \beta\varphi)}$$

Taking derivative of the right hand side with respect to g_B, it can be obtained that $\frac{\partial}{\partial g_B}\left(\frac{L_1}{L_2}\right) > 0$ if $b_1 > b_2$ and $\frac{(a_2-a_1)(1-\beta+\beta\varphi)}{1-\beta+\beta\varphi-\beta\varphi d} < b_1 - b_2 < \frac{a_2-a_1}{1-\beta d}$.

A.2.3 Constant Return to Scale at the Sectoral Level

In the multiple firm model, recall that the production function of firm j in sector i is

$$y_{ji,t} = \left[k_{ji,t}^{a_i} o_{ji,t}^{b_i} l_{y_{ji},t}^{1-a_i-b_i}\right]^v - F_i, \qquad 0 < j < n_i$$

In the equilibrium, the relative levels of output and input for all firms in sector i are given by

$$\begin{aligned} \frac{y_{ji}}{y_{ki}} &= \frac{k_{ji}}{k_{ki}} = \frac{l_{y_{ji}}}{l_{y_{ki}}} = \left(\frac{B_{ji}}{B_{ki}}\right)^{\frac{b_i v}{1-v+(1-d)b_i v}} \\ \frac{o_{ji}}{o_{ki}} &= \left(\frac{B_{ji}}{B_{ki}}\right)^{\frac{1-v+b_i v}{1-v+(1-d)b_i v}} \end{aligned}$$

This implies a sector level production function of the form

$$Y_i = \left(K_i^{a_i} O_i^{b_i} L_{y_i}^{1-a_i-b_i}\right)^v n_i^{1-v} - n_i F_i \tag{27}$$

The equilibrium number of firms is determined by taking derivative of the above function with respect to n_i :

$$n_i = \frac{(1-v)^{1/v} K_i^{a_i} O_i^{b_i} L_{y_i}^{1-a_i-b_i}}{F_i^{1/v}}$$

Plug it into Equation 27 to obtain the sectoral production function

$$Y_i = v\left(\frac{1-v}{F_i}\right)^{\frac{1-v}{v}} K_i^{a_i} O_i^{b_i} L_{y_i}^{1-a_i-b_i}$$

which displays constant return to scale.

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