Intangible Capital and the Origin of Modern Structural Change

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September 2009
(Preliminary and incomplete. Comments welcomed.)

Abstract

This paper presents theory and evidence about the ongoing sectoral structural change in the US economy based on intangible capital accumulation.

The sectoral composition of US economy has shifted dramatically in the recent decades. I argue that a ready explanation for this structural transformation lies in the difference of intangible capital intensity across sectors. The two-sector model of the paper shows that as the productivity of intangible capital investment increases, labor is shifted from direct goods production tasks to creating sector-specific intangible capital. In the process, the real output and employment shares increase for the intangible-capital intensive sector. The model simulation generates realistic scale of sectoral composition change that fully matches the magnitude of increasing output share for the intangible capital intensive sector in the US, and can account for 65% of the sector's employment share increase.

The empirical exercise of the paper finds 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, which is more intangible capital intensive. 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 shows that 86% of the rise of service sector output can be accounted for by high intangible capital industries.

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. The first fact is that 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 their intangible capital investment intensity. 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.

The second fact is that the intangible capital investment for the growing industries rises faster, in general, than that of the declining industries. Figure 1b shows the trend of intangible capital investment for the growing and shrinking sectors in the US. Here, industries are divided into two sectors according to whether their real output shares have increased or not over the sample period. 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.

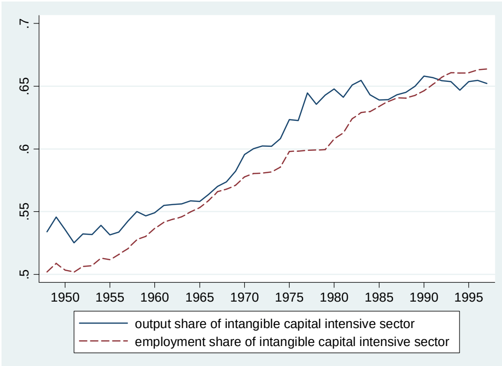

Figure 1a: Shares of the intangible capital intensive sector

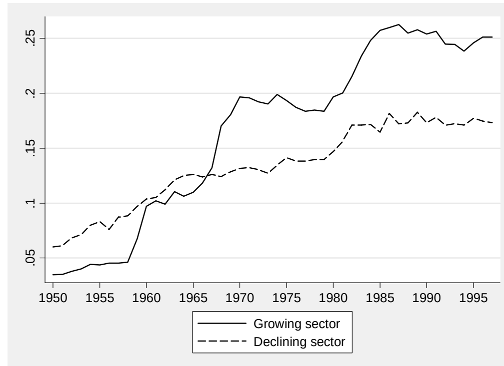

Figure 1b: Intangible capital investment intensity

The third stylized fact is that employment is shifting from direct goods production to intangible capital investment activities in recent decades. 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.[2]

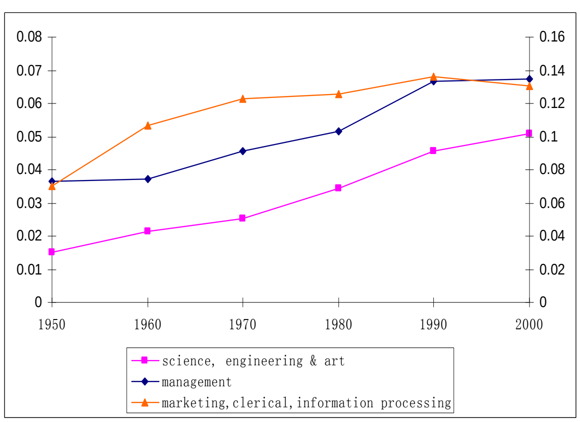

Figure 2: Rise of employment engaging in intangible capital investment

[2]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 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 reviews of both structural change literature and intangible capital investment 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.[3] The present paper, to my best knowledge,

[3] 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)

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 function is Cobb-Douglas:

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

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. For the rest of the paper, I assume that sector 1 is more intangible capital intensive, that is, $b_1 - b_2 > 0$.

Physical capital and labor are freely mobile across sectors. To allow for a simple, closed-form solution to 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, simplifies the solution of the model and allows us to focus more on the main story of the model, i.e., the difference of intangible capital accumulation across sectors.

Intangible capital accumulation function is also log-linear. But it is accumulated within a sector and is not directly transferrable between the two sectors

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

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.

$X_{i,t}$ is the current period investment in sector i's intangible capital. The production function for X_i is

$$X_{i,t} = \left(\overline{X_i} + B_{i,t}L_{o_i,t}\right)^d$$

Here I assume that to produce X_i, it only requires labor input:L_{o_i}. d is a constant between 0 and 1, and $\overline{X_i}$ is a positive constant number. Therefore, if $L_{o_i,t} = 0$, $X_{i,t} = \overline{X_i}^d$. The idea is that even if there is no deliberate efforts made in the sector into building intangible assets, intangible capital, such as tacit know-hows, information about employees, can still accumulates, as a form of positive externality of goods production process. $B_{i,t}$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}. In other words, $B_{i,t} = B_{i,t-1}(1 + g_{B_i})$.

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

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

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

$$C_t + I_t \leq Y_t$$

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

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

From the first order conditions,[4] it can be derived that the ratio of physical capital allocated

[4]Specified in the appendix.

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:

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

3.2 Comparative Statics

The Euler equation for intangible capital accumulation can be written as

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

The labor hired in sector 1 can be seen as the sum of labor engaged in sectoral goods production and in intangible capital creation. It can be proved that in the steady state, sector 1's share of labor is increasing in sector 1's intangible investment productivity, and decreasing in sector 2's intangible investment productivity:

Proposition 1 *Let $L_1 = L_{y_1} + L_{o_1}$. Suppose that in the steady state, $B_{i,t} = B_{i,t+1} = B_i$, then $\frac{\partial L_1}{\partial B_1} > 0$, and $\frac{\partial L_1}{\partial B_2} < 0$.*

If we assume that the steady-state investment productivities are the same in both sectors, it can be derived that sector 1's shares of both output and labor increase with the intangible investment productivity:

Proposition 2 *Suppose that $B_1 = B_2 = B$. The output share of the intangible-capital-intensive sector increases with the intangible investment productivity: $\frac{\partial(Y_1/Y_2)}{\partial B} > 0$. Let $\Phi_1 = 1+\frac{\gamma_2(1-a_2-b_2)}{\gamma_1(1-a_1-b_1)}+\frac{\beta b_1 d\varphi}{(1-a_1-b_1)[1-\beta(1-\varphi)]}+\frac{\beta b_2 d\varphi}{1-\beta(1-\varphi)}\frac{\gamma_2}{\gamma_1(1-a_1-b_1)}$. If $\overline{X}_1 - \frac{\overline{X}_1+\overline{X}_2}{\Phi_1} - \frac{\beta b_1 d\varphi}{(1-a_1-b_1)[1-\beta(1-\varphi)]}\frac{\overline{X}_1+\overline{X}_2}{\Phi_1} > 0$, the employment share of the intangible-capital-intensive sector increases with the intangible investment productivity: $\frac{\partial(L_1/L_2)}{\partial B} > 0$.*

It can also be shown that the intangible investments in both sectors are increasing in B, $\frac{\partial X_i}{\partial B} > 0$. However, the investment ratio between the two sectors does not depend on the level of B :

Proposition 3 *Given that $B_1 = B_2 = B$, the intangible investment ratio between the two sectors is a function of sectors' shares in the final goods production function and their intangible capital intensities: $\frac{X_1}{X_2} = \left(\frac{\gamma_1}{\gamma_2}\right)^d \left(\frac{b_1}{b_2}\right)^d$.*

The proof for the above propositions are included in Appendix A2.

The considerable increase of intangible capital investment since the 1950s suggests that the investment productivity has mostly like experienced significant growth. Although the value of B is not directly observed, assuming that B has increased in that past fifty years and this increase is shared by all sectors, we can empirically test proposition 2 by examining whether high intangible sectors' output and employment shares have gone up during this period.

To do this, we need to identify a sector's intangible capital intensity, i.e., the value of b_i. This variable is not directly observed either. However, according to proposition 3, there is a positive linkage between the amount of X_i and sector i's intangible capital intensity, b_i. Proposition 3 thus offers a way to identify the relative value of b_i from the relative quantity of intangible investment of a sector. The empirical section of the paper implemented this strategy to rank the intangible capital intensity for SIC 2 digit industries, and test the prediciton of Proposition 2 at the industry level.

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

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

where $0 < \eta < 1$, 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.

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

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

where x_i is a constant. B_{ji} is the intangible investment productivity of firm j in sector i. Intangible investment productivity is normally distributed across the firms in a sector, $B_{ji}\tilde{}N\left(\overline{B}_i, \sigma_{B_i}^2\right)$. I further assume that the distribution coefficients are the same in the two sectors: $\overline{B}_1 = \overline{B}_2; \sigma_{B_1}^2 = \sigma_{B_2}^2$.

The appendix will show that when there are more than one firm in a sector, individual firms' outputs and employment decisions can be aggregated to the sectoral level decision rule, which takes the same form as derived in the baseline model. This guarantees that the comparative static results in the previous section still hold. In addition, the following propositions can be derived from the steady-state equilibrium of the multiple-firm model.

Proposition 4 *In the steady state, the size of firm output is increasing in a firm's intangible investment productivity:* $\frac{\partial y_{ji}}{\partial B_{ji}} > 0$. *Let the size of firm employment* $l_{ji} = l_{y_{ji}} + l_{o_{ji}}$. l_{ji} *is* *also increasing in firm's intangible investment productivity:* $\frac{\partial l_{ji}}{\partial B_{ji}} > 0$.

Proposition 5 *B_{ji}'s impact on firm's output and employment is increasing in the sector's intangible capital intensity:*$\frac{\partial^2 y_{ji}}{\partial B_{ji} \partial b_i} > 0$, $\frac{\partial^2 l_{ji}}{\partial B_{ji} \partial b_i} > 0$.

The proofs for the above propositions are included in Appendix A3. The predictions of Proposition 4 and 5 can be tested using firm level data. Note that although the productivity B_{ji} is not directly observed, the intangible investment X_{ji} is an increasing function of B_{ji}. Therefore, assuming firms in the same sector share the same production function coefficients, we can use X_{ji} as an indicator for the level of B_{ji}. We can then ask whether firm's output and employment are positively correlated with intangible capital investment, and if so, whether this correlation is higher in the intangible-capital-intensive sector. The firm-level empirical analysis section will explain the regression specification in more details.

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 1 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 1: Sector categorization according to intangible capital intensity (1950-1997)

I assume that the initial year $t = 0$ corresponds to the year 1950 in reality, when firm SG&A data was first available. I normalize the initial labor supply L_0 to 1. The total employment growth data of the industries covered here indicates an average annual labor supply growth rate $g_L = 0.0178$. In the baseline calibration, I set the productivity of intangible capital production at t_0 to be the same in both sectors:$B_{10} = B_{20} = 0.0047$. I will investigate alternative assumptions of these parameters in the sensitivity analysis section later.

The rest of the parameters that need to be decided–13 in all– are the following: $\beta, \{d_i, \gamma_i, a_i, b_i, \overline{X}_i\}_{i=1,2}, \delta, \varphi$. Physical capital's share in the sectoral production function is calibrated as the average industry capital income over value-added in each sector. Assume that sector 1 is the intangible capital intensive sector. It implies that $a_1 = 0.39$ and $a_2 = 0.41$. Intangible capital's shares b_1 and b_2 are set to be the average industry SG&A/sales ratio within each sector, which are equal to 0.24 and 0.13 respectively. 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 $\delta = 0.1$. 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 1950. This leads to $\gamma_1 = 0.65$ and $\gamma_2 = 0.35$. I choose the values of $\overline{X}_1$ and $\overline{X}_2$ to be equal to 0.00135 and 0.00001 to make sure that in the initial steady-state, labor allocated to producing intangible capital and sectoral goods in both sectors are bounded above 0 and the employment ratio between the two sectors is close to the initial year's data. Finally, d_i, the measure of decreasing return to scale for intangible capital investment is assumed to be 0.9 for both sectors.

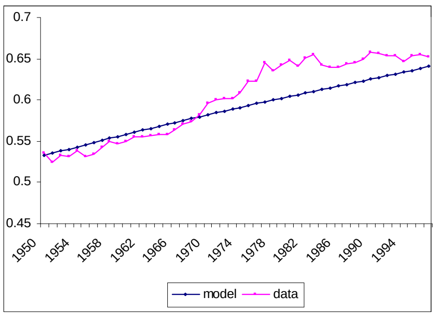

Figure 3a: Output share of sector 1

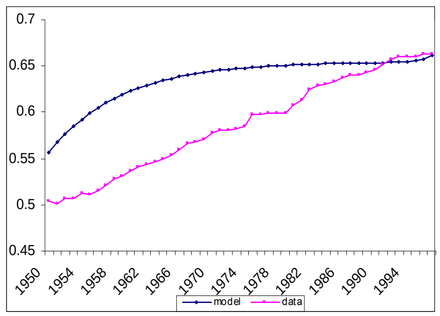

Figure 3b: Employment share of sector 1

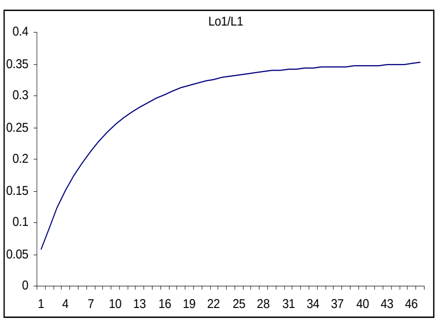

Figure 4a: Labor engaged in intangible capital creation as a proportion of total employment in sector 1

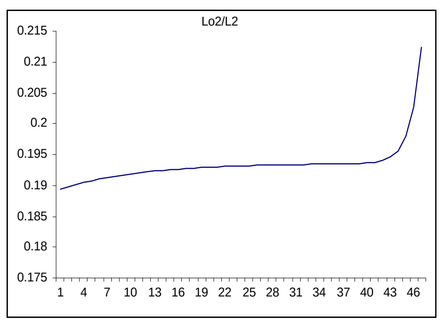

Figure 4b: Labor engaged in intangible capital creation as a proportion of total employment in sector 2

Figure 3a and 3b display the calibration results for the output and employment shares of sector 1– the intangible capital intensive sector– with the parameter values specified above, for the first 47 years. The annual intangible investment productivity growth in this simulation is set at $g_B = 0.1$ for both sectors. 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 0.53 to 0.64, roughly the same magnitude as in the data. On the employment side, the share of sector 1 rose from 0.57 in the beginning period to 0.66 at the end of the time window, the magnitude of increase is about 65% of that in the data. Figure 4a and 4b present the ratio of the amount of labor allocated to sectoral intangible capital investment over the total labor force employed in that sector. They show that in both sectors, labor is shifted over time from producing sectoral goods to producing intangible capital. And this shift is of a larger magnitude in sector 1, where intangible capital is 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. And it is also consistent with the stylized fact I presented in the introduction part.

Next, let's look at the long-run convergence of the model economy. Figure 5 extends the plots of sector 1's employment and output shares to 120 periods. With the baseline parameter values, the employment share of sector 1 reaches its long-run equilibrium of 0.915 after about 130 years from the beginning period. Its output share takes 280 years to reach the asymptotic equilibrium level, 1. However, as we shall see later, the asymptotic level of sector 1's labor share and the direction of its long-term trend are actually quite sensitive to the parameter choices. I will discuss this in the next section.

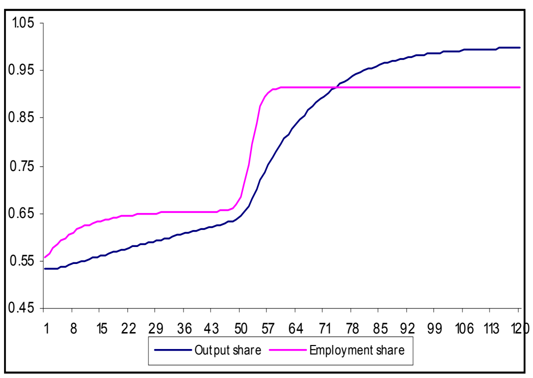

Figure 5: Shares of sector 1 in the long run

4.2 Sensitivity Analysis

In this section, I apply alternative parameter values to the calibration of the model. As we will see, the long-run trend of labor allocation crucially depends on assumptions about intangible capital investment productivity.

First, I changed the starting value of intangible investment productivity. Figure 6a and 6b show the trend of sector 1's output and employment shares in the two scenarios where B_0 is changed to 0.0053 and 0.0055 for both sectors. A few comments are in order. The trend of sector 1's output share doesn't alter much despite the changes in B_0– it converges to 1, taking roughly the same time as in the baseline calibration. However, the trend of sector 1's employment share behaves quite differently in the alternative scenarios. For the first 50 years, more labor is allocated to the intangible capital intensive sector, similar to the baseline case. After that, labor allocation trend displays significant difference with altered choices of B_0. In the first alternative case, sector 1's employment share converges to a lower level than in the baseline scenario, but still higher than in the initial state. In the second scenario, the initial rising trend is eventually reversed. Why would the trend of labor allocation change with different choices of B_0? The intuition is the following. In the beginning when the intangible investment productivity just starts to rise, something similar to the substitution effect is dominant. The agent wants to take advantage of the productivity increase and invest more in the sector where intangible capital– which is now more efficiently produced– has a larger impact in the sectoral goods production. However, when the investment productivity rises to a certain level, in order to achieve maximized utility, it might be more optimal to allocate more labor to the sector whose output level is lagging behind.

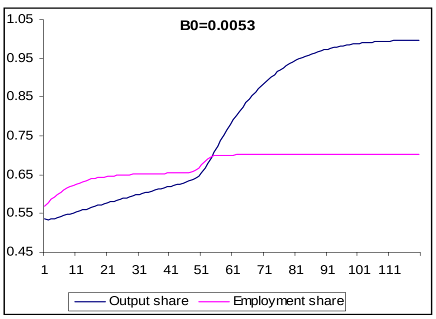

Figure 6a: Alternative value for B0

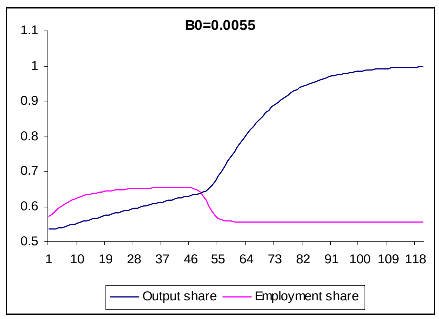

Figure 6b: Alternative value for B0

The trend of the sectoral composition for employment is also sensitive to the growth rate of intangible investment productivity. Figure 7a and 7b plot the employment and output shares for sector 1 when the annual growth rate of B_t is equal to 1.01 and 1.09. Here we see similar changes as in the previous scenario. The long-term trend of output share of sector 1 doesn't vary much with changes in the growth rate of productivity, while the trend of its employment share is quite responsive to changes in the productivity growth rate.

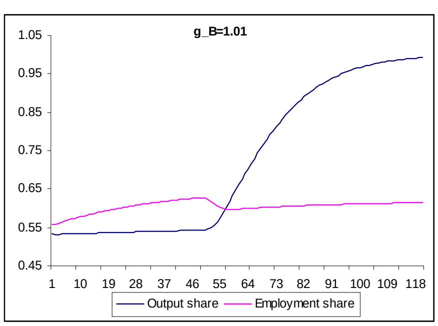

Figure 7a: Alternative value for the growth rate of B

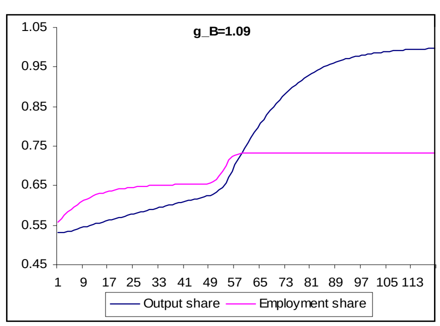

Figure 7b: Alternative value for the growth rate of B

Overall, the calibration exercise indicates that the mechanism adopted in the model can generate sectoral structural change in real output that is very close to the US data. The model can also produce employment allocation change between sectors that is generally in line with the data. It is also interesting to note that although the simulation of the model matched the increasing employment share of the intangible capital intensive sector in historical data, the model's prediction for long-run sectoral composition of employment crucially depends on the growth characteristics of intangible capital investment productivity, which shed light on the possible directions of future structural change of the economy.

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, as predicted by Proposition 4, and whether such a relationship is stronger in the high-intangible-capital sector, as Proposition 5 claims. 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 is conducted at industry level. It 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 Proposition 2 in the earlier section. 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 2, 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 2: 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 Proposition 4, the firms with higher intangible productivity have higher output/employment, compared to their peers in the same sector. 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 future output/employment level. Furthermore, Proposition 5 predicts that the positive correlation between intangible investment productivity and a firm's output/employment is higher in the intangible capital intensive sector. To test these hypotheses, I estimate the following empirical regression:

$$\begin{aligned} g_{y_{ij},t} &= \beta_0 + \beta_1 \left(\frac{SG\&A}{Y}\right)_{ij,t-1} + \beta_2 \left(\frac{SG\&A}{Y}\right)_{ij,t-1} \times \text{growsec} + \beta_3 \left(\frac{I_k}{Y}\right)_{ij,t-1} \\ &\quad + \beta_4 \left(\frac{I_i}{Y}\right)_{ij,t-1} \times \text{growsec} + \beta_5 \text{growsec} + \beta_6 control_{ij,t-1} + u_{ij,t} \qquad (3) \end{aligned}$$

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 and 5, 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

$$\begin{aligned} g_{l_{ij},t} &= \gamma_0 + \gamma_1 \left(\frac{SG\&A}{Y}\right)_{ij,t-1} + \gamma_2 \left(\frac{SG\&A}{Y}\right)_{ij,t-1} \times \text{growsec} + \gamma_3 \left(\frac{I_k}{Y}\right)_{ij,t-1} \\ &\quad + \gamma_4 \left(\frac{I_i}{Y}\right)_{ij,t-1} \times \text{growsec} + \gamma_5 \text{growsec} + \gamma_6 control_{ij,t-1} + \omega_{ij,t} \end{aligned} \tag{4}$$

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.[5]

[5] 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.

5.3.2 Industry Level Model

Proposition 2 in the theoretical model suggests that the intangible-capital-intensive sector's real output and employment are increasing in the intangible investment productivity B of the economy. The simulation of the model also shows that the intangible-capital-intensive sector expands during periods of investment productivity growth. At an industry-level regression setting, this implies a positive relationship between industry i's share growth and its intangible capital intensity, b_i. Proposition 3 shows that the relative level of b_i can be inferred 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:

$$\begin{aligned} g\_yshare_{j,t-s,t} &= \chi_0 + \chi_1 g\_yshare_{j,t-1-s,t-1} + \chi_2 INDEX\_SGA_{j,t-s} + \chi_3 INDEX\_K_{j,t-s} \\ &\quad + \chi_4 INDEX\_EDU_{j,t-s} + \chi_5 INDEX\_IT_{j,t-s} + \upsilon_{j,t} \qquad (5) \end{aligned}$$

$$\begin{aligned} g\_lshare_{j,t-s,t} &= \lambda_0 + \lambda_1 g\_lshare_{j,t-1-s,t-1} + \lambda_2 INDEX\_SGA_{j,t-s} + \lambda_3 INDEX\_K_{j,t-s} \\ &\quad + \lambda_4 INDEX\_EDU_{j,t-s} + \lambda_5 INDEX\_IT_{j,t-s} + \eta_{j,t} \qquad (6) \end{aligned}$$

$g\_yshare_{j,t-s,t}$ 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 3a and 3b present the results for the firm-level regressions– equation 3 and 4. Both OLS and panel regression coefficients are reported. Table 4 presents the results of industry-level regressions– equation 5 and 6, 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 3a, 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 3a: Impact of Intangible capital investment on firm sales (specification 1)

The results in Table 3b 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 3b: Impact of Intangible capital investment on firm employment (specification 1)

Table 4 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 4: 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:

$$\begin{aligned}\left(\frac{Y}{A}\right)_{ij,t} &= \alpha_0 + \alpha_1\left(\frac{SG\&A}{A}\right)_{ij,t} + \alpha_2\left(\frac{SG\&A}{A}\right)_{ij,t-1} + \alpha_3\left(\frac{SG\&A}{A}\right)_{ij,t} \times \text{growsec} \\ &+\alpha_4\left(\frac{SG\&A}{A}\right)_{ij,t-1} \times \text{growsec} + \alpha_5\left(\frac{I_k}{A}\right)_{ij,t} + \alpha_6\left(\frac{I_k}{A}\right)_{ij,t-1} \\ &+\alpha_7\left(\frac{I_k}{A}\right)_{ij,t} \times \text{growsec} + \alpha_8\left(\frac{I_k}{A}\right)_{ij,t-1} \times \text{growsec} + \alpha_9\text{growsec} + \alpha_{10} control_{ij,t} + e_{ij,t}\end{aligned} \tag{7}$$

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

$$\begin{aligned}\left(\frac{L}{A}\right)_{ij,t} = & \lambda_0 + \lambda_1\left(\frac{SG\&A}{A}\right)_{ij,t} + \lambda_2\left(\frac{SG\&A}{A}\right)_{ij,t-1} + \lambda_3\left(\frac{SG\&A}{A}\right)_{ij,t} \times \text{growsec} \\ & + \lambda_4\left(\frac{SG\&A}{A}\right)_{ij,t-1} \times \text{growsec} + \lambda_5\left(\frac{I_k}{A}\right)_{ij,t} + \lambda_6\left(\frac{I_k}{A}\right)_{ij,t-1} \\ & + \lambda_7\left(\frac{I_k}{A}\right)_{ij,t} \times \text{growsec} + \lambda_8\left(\frac{I_k}{A}\right)_{ij,t-1} \times \text{growsec} + \lambda_9\text{growsec} + \lambda_{10}control_{ij,t} + e_{ij,t}\end{aligned} \tag{8}$$

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 5a and 5b, 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 growthing sector. Its relationship with employment is mixed.

	Sales/t.a $_t$			
	model1	model2	model3	model4
$(sg\&a/t.a.)_t$	0.188***	0.188***	0.629***	0.567***
	(157.26)	(161.28)	(129.83)	(113.98)
$(sg\&a/t.a.)_{t-1}$	0.354***	0.323***	-0.003	-0.003
	(181.56)	(163.86)	(-1.31)	(-1.51)
$(I_K/t.a.)_t$	0.064***	0.068***	-0.039**	0.040**
	(7.45)	(8.03)	(-2.69)	(2.75)
$(I_K/t.a.)_{t-1}$	-0.089***	-0.070***	-0.024	0.040**
	(-10.61)	(-8.47)	(-1.78)	(2.95)
$(sg\&a/t.a.) \times growsec_t$			-0.262***	-0.209***
			(-51.46)	(-40.16)
$(sg\&a/t.a.) \times growsec_{t-1}$			0.022***	0.017***
			(8.37)	(6.48)
$(I_K/t.a.) \times growsec_t$			0.037*	-0.088***
			(2.1)	(-4.94)
$(I_K/t.a.) \times growsec_{t-1}$			-0.002	-0.117***
			(-0.14)	(-6.92)
growsec			0.091***	0.056
			(32.28)	(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 5a: Impact of Intangible capital investment on firm sales

	Employment/t.a $_t$			
	model1	model2	model3	model4
$(sg\&a/t.a.)_t$	-0.004***	-0.003***	0.016***	0.015***
	(-11.58)	(-8.94)	(7.65)	(6.96)
$(sg\&a/t.a.)_{t-1}$	0.003***	0.003***	-0.0003	-0.00001
	(7.83)	(6.83)	(-0.34)	(-0.01)
$(I_K/t.a.)_t$	0.012**	0.002	-0.009	0.0002
	(3.12)	(0.56)	(-1.34)	(0.04)
$(I_K/t.a.)_{t-1}$	0.002	-0.005	-0.011	-0.001
	(0.58)	(-1.33)	(-1.69)	(-0.15)
$(sg\&a/t.a.) \times growsec_t$			-0.021***	-0.019***
			(-9.8)	(-8.62)
$(sg\&a/t.a.) \times growsec_{t-1}$			0.003**	0.003**
			(3.14)	(2.75)
$(I_K/t.a.) \times growsec_t$			0.034***	0.002
			(4.26)	(0.27)
$(I_K/t.a.) \times growsec_{t-1}$			0.021**	-0.006
			(2.75)	(-0.8)
growsec			-0.0008	-0.006
			(-0.63)	(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 5b: 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 8.

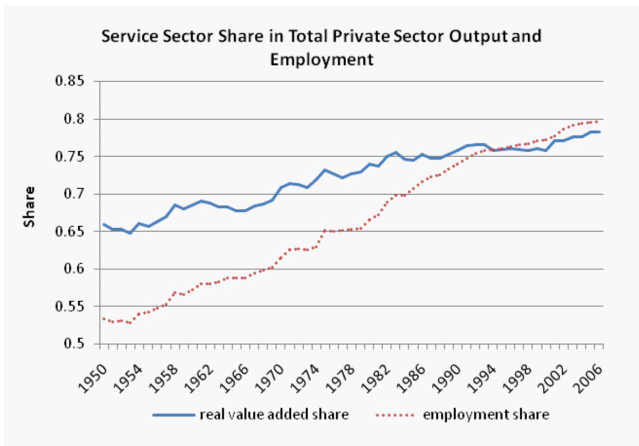

Figure 8: Service Sector Share of Real Output and Employment

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 6a and 6b 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 6a and 6b 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 9 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 6a: 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 6b: IC Intensity of Declining Service Industries (1977-2007)

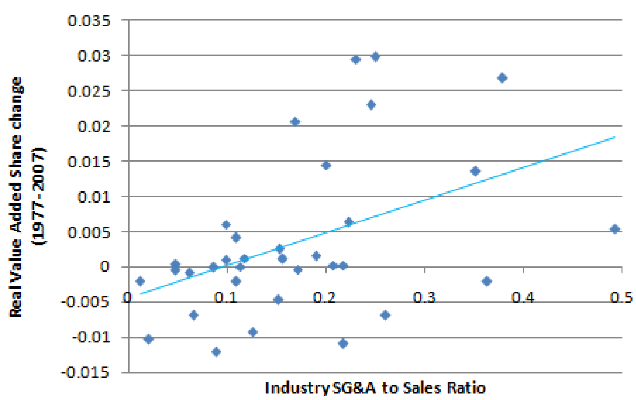

Figure 9: Service Inudustries' Growth and Intangible Capital Intensity

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 composition change in US economy during the recent decades. I argued that the differences in intangible capital accumulation across sectors is an important source of structural change. In the two-sector model of the paper, the importance of intangible capital in the production function differs across sectors. There are two kinds of work tasks in the model economy: directly producing sectoral goods and creating intangible capital investment for future production. As the productivity of intangible capital investment increases, the model predicts that both sectors invest more in intangible capital, and that that output of the intangible capital intensive sector grows faster than that of the low intangible sector. At the same time, as labor is shifted to intangible assets production, and more so in the intangible capital intensive sector, this sector's total employment also increases relative to the other 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 share increase of the intangible capital intensive sector that quantitatively matches the empirical data from 1950 to late 1990s.

Empirical estimations are conducted at firm and industry level to test the theory. The firm-level regressions indicate that 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.

Finally, the theory developed in this paper can help explain the growth of service sector in particular, as evidence suggesting that the intangible-capital-intensive industries constitute most of the growing part of the service sector.

A Appendix

A.1 Solving the Planner's Problem

First order conditions for the planner's problem:

$$C_t : \quad \lambda_t = 1/C_t \tag{9}$$

$$Y_{it} : \quad \mu_{it} = \lambda_t \gamma_i \frac{Y_t}{Y_{it}} \tag{10}$$

$$K_{it} : \quad \xi_t = \mu_{it} a_i \frac{Y_{it}}{K_{it}} \tag{11}$$

$$L_{y_i,t} : \quad \eta_t = \mu_{it} \left(1 - a_i - b_i\right) \frac{Y_{it}}{L_{y_i,t}} \tag{12}$$

$$L_{o_{it}}: \quad \eta_t = \phi_{it} d_i \varphi O_{it}^{1-\varphi} \left(\overline{X_i} + B_{it} L_{o_it}\right)^{d\varphi - 1} B_{it} \tag{13}$$

$$K_{t+1} \quad : \quad \frac{\lambda_t}{\delta} \frac{I_t}{K_{t+1}} = \beta \left[\lambda_{t+1} \frac{1-\delta}{\delta} \frac{I_{t+1}}{K_{t+1}} + \xi_{t+1}\right] \tag{14}$$

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

$$O_{i,t+1}: \ \phi_{it} = \beta \left[\mu_{i,t+1} b_i \frac{Y_{i,t+1}}{O_{i,t+1}} + \phi_{i,t+1} (1-\varphi) O_{i,t+1}^{-\varphi} \left(\overline{X_i} + B_{i,t+1} L_{o_i,t+1}\right)^{d\varphi}\right] \tag{15}$$

Let $S_c = C_t / Y_t$, (9),(10),(14)$\Longrightarrow$

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

(13),(12),(10)$\Longrightarrow$

$$\phi_{it} = \frac{\lambda_t \gamma_i \frac{Y_t}{L_{y_i,t}} (1 - a_i - b_i)}{d_i \varphi O_{it}^{1-\varphi} \left(\overline{X_i} + B_{it} L_{o_it}\right)^{d\varphi-1} B_{it}} \Longrightarrow \frac{\overline{X_i} + B_{i,t} L_{o_i,t}}{B_{i,t} L_{y_i,t}} = \frac{\beta b_i d\varphi}{1 - a_i - b_i} + \frac{\beta(1-\varphi)(\overline{X_i} + B_{i,t+1} L_{o_i,t+1})}{B_{i,t+1} L_{y_i,t+1}}$$

A.2 Comparative Statics Results of the baseline model

Suppose in the steady state, $B_{i,t} = B_{i,t+1} = B_i$. The steady state relationship between $L_{o_i}$and L_{y_i} is

$$L_{o_i} = \frac{\beta b_i d\varphi}{1 - a_i - b_i} \frac{1}{1 - \beta(1-\varphi)} L_{y_i} - \frac{\overline{X_i}}{B_i} \qquad i = 1, 2 \tag{16}$$

Combining equation (1), (2) and (16), we have

$$L_{y_1} = \left[\overline{L}_t + \frac{\overline{X}_1}{B_1} + \frac{\overline{X}_2}{B_2}\right] / \Phi_1$$

where $\Phi_1 = 1 + \frac{\gamma_2(1-a_2-b_2)}{\gamma_1(1-a_1-b_1)} + \frac{\beta b_1 d\varphi}{(1-a_1-b_1)[1-\beta(1-\varphi)]} + \frac{\beta b_2 d\varphi}{1-\beta(1-\varphi)} \frac{\gamma_2}{\gamma_1(1-a_1-b_1)}$.

Denote the labor hired in sector 1 as the sum of labor engaged in sectoral good production and in intangible capital creation, i.e., $L_1 = L_{y_1} + L_{o_1}$. We have

$$L_1 = \frac{[1 + \frac{\beta b_1 d\varphi}{(1-a_1-b_1)[1-\beta(1-\varphi)]}][\overline{L}_t + \frac{\overline{X}_1}{B_1} + \frac{\overline{X}_2}{B_2}]}{\Phi} - \frac{\overline{X}_1}{B_1}$$

It is easy to see that$\frac{\partial L_1}{\partial B_1} > 0$, and$\frac{\partial L_1}{\partial B_2} < 0$.

Now suppose that in the steady state, the two sectors have the same productivity level, that is, $B_1 = B_2 = B$. Rewrite L_1 as

$$L_1 = \frac{[1 + \frac{\beta b_1 d\varphi}{(1-a_1-b_1)[1-\beta(1-\varphi)]}][\overline{L}_t + \frac{\overline{X}_1 + \overline{X}_2}{B}]}{\Phi} - \frac{\overline{X}_1}{B},$$

Take the derivative of $L_1$with respect to B,

$$\frac{\partial L_1}{\partial B} = [\overline{X}_1 - \frac{\overline{X}_1 + \overline{X}_2}{\Phi} - \frac{\beta b_1 d\varphi}{(1-a_1-b_1)[1-\beta(1-\varphi)]}\frac{\overline{X}_1 + \overline{X}_2}{\Phi}]\frac{1}{B^2}$$

Then we can get

$$\frac{\partial L_1}{\partial B} > 0 \Longleftrightarrow \overline{X}_1 - \frac{\overline{X}_1 + \overline{X}_2}{\Phi} - \frac{\beta b_1 d\varphi}{(1-a_1-b_1)[1-\beta(1-\varphi)]}\frac{\overline{X}_1 + \overline{X}_2}{\Phi} > 0$$

In other words, given certain requirements on parameters, the relative size of employment for the intangible capital intensive sector increases with the steady-state intangible investment productivity.

From (16) and the production function for intangible capital investment, the steady-state X_i is equal to

$$X_i = \left[\frac{\beta b_i d\varphi}{1-a_i-b_i}\frac{B}{1-\beta(1-\varphi)}L_{y_i}\right]^d \tag{17}$$

Since $\frac{L_{y1}}{L_{y2}} = \frac{\gamma_1(1-a_1-b_1)}{\gamma_2(1-a_2-b_2)}$, the ratio of intangible investment between the two sectors is

$$\frac{X_1}{X_2} = \left(\frac{\gamma_1}{\gamma_2}\right)^d \left(\frac{b_1}{b_2}\right)^d$$

In other words, the intangible investment ratio between the two sectors in the steady state is an increasing function of the ratio $\frac{b_1}{b_2}$ and $\frac{\gamma_1}{\gamma_2}$. It does not depend on investment productivity B.

In the steady state, $O_i = X_i$. Therefore, expression (17), combined with the equilibrium values of L_{y_i} and K_i, gives us the steady-state value of Y_i as a function of $K, \overline{L}$, and B. It is easy to show that:

$$\frac{\partial\left(Y_1/Y_2\right)}{\partial B} > 0$$

That is, the relative size of output for the intangible capital intensive sector also increases with the steady-state level intangible investment productivity.

A.3 Results of the Multiple-Firm Model

In this extension of the baseline model, I allow for multiple firms in each sector. All firms in sector i share the same production function

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

where $0 < \eta < 1$, 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 a measure of the number of firms in sector i.

Physical capital and labor are mobile across firms. But each firm must accumulate its own intangible capital:

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

where x_i is a constant.

From the intratemporal first order conditions of the social planner's problem, we have

$$\frac{y_{ji,t}}{y_{ki,t}} = \frac{k_{ji,t}}{k_{ki,t}} = \frac{l_{y_{ji},t}}{l_{y_{ki},t}}, \text{ for firm } j \text{ and } k \text{ in sector } i. \quad 0 < j, k \leq n_i$$

The Euler equation of intangible capital accumulation for firm j in sector i is

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

In the steady state, assuming that $B_{ji,t} = B_{ji}$, each firm produces a constant share of sectoral output. More specifically, we have

$$\frac{x_i + B_{ji} l_{o_{ji}}}{B_{ji} l_{y_{ji}}} = \frac{x_i + B_{ki} l_{o_{ji}}}{B_{ki} l_{y_{ki}}}, \text{ for any firm } j \text{ and } k \text{ in sector } i.$$

Rearranging the equation:

$$\frac{x_i + B_{ji} l_{o_{ji}}}{x_i + B_{ki} l_{o_{ki}}} = \frac{B_{ji} l_{y_{ji}}}{B_{ki} l_{y_{ki}}}$$

Since in the steady state, $o_{ji} = x_{ji}$,

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

Therefore,

$$\frac{y_{ji}}{y_{ki}} = f(B_{ji}/B_{ki}, b_i) = \left(\frac{B_{ji}}{B_{ki}}\right)^{\frac{d\eta b_i}{1-\eta+(1-d)\eta b_i}}$$

Without losses of generality, let's normalize B_{ki} to 1 and let y_{ki} be equal to y_i. Then we have

$$y_{ji} = y_i B_{ji}^{\frac{d\eta b_i}{1-\eta+(1-d)\eta b_i}}, \qquad j = 1, 2, ..., n_i$$

In other words, given sectoral parameters, a firm's output is an increasing function of its intangible investment productivity. And it is straightforward to show that

$$\frac{\partial^2 y_{ji}}{\partial B_{ji} \partial b_i} > 0.$$

That is, the impact of intangible investment productivity on firm's output level is increasing in the share of intangible capital in sector i's production function, b_i

Similar derivation on the employment side yields that

$$l_{ji} = l_{y_j,i} + l_{o_j,i} = l_i B_{ji}^{\frac{d\eta b_i}{1-\eta+(1-d)\eta b_i}} - \frac{x_i}{B_{ji}}, \qquad j = 1, 2, ..., n_i$$

where l_i is the normalized firm k's employment. It is clear that the firm's employment is also increasing in its intangible investment productivity, and $\frac{\partial^2 l_{ji}}{\partial B_{ji} \partial b_i} > 0$.

Since all firms in a sector use production inputs in the same proportions,

$$Y_{i,t} = \sum_{j=1}^{n_i} (k_{ji,t}^{a_i} o_{ji,t}^{b_i} l_{y_{ji},t}^{1-a_i-b_i})^\eta - n_i F_i = n_i^{1-\eta} (K_{i,t}^{a_i} O_{i,t}^{b_i} L_{y_i,t}^{1-a_i-b_i})^\eta - n_i F_i$$

Assuming that in the steady state, the number of firms in each sector is optimal, i.e., it maximizes the sectoral output, then n_i can be calculated through the first order condition $\frac{\partial Y_i}{\partial n_i} = 0$. The optimal n_i is

$$n_i = (\frac{1-\eta}{F_i})^{\frac{1}{\eta}} K_{i,t}^{a_i} O_{i,t}^{b_i} L_{y_i,t}^{1-a_i-b_i}$$

Plug it into the expression for $Y_{i,t}$, we have

$$Y_{i,t} = \eta (\frac{1-\eta}{F_i})^{\frac{1-\eta}{\eta}} K_{i,t}^{a_i} O_{i,t}^{b_i} L_{y_i,t}^{1-a_i-b_i}$$

Therefore, the individual firms' production functions can aggregate to the sectoral production function that coincides with the single firm scenario in section 3.

For firm j and firm k in sector i, in the steady state

$$\frac{x_i + B_{ki} l_{o_{ki}}}{x_i + B_{ji} l_{o_{ji}}} = \left(\frac{B_{ki}}{B_{ji}} \right)^{\frac{1-\eta+\eta b_i}{1-\eta+(1-d)\eta b_i}}$$

Thus we have

$$
\begin{aligned}
l_{o_{ki}} &= \frac{1}{B_{ki}}\left(\frac{B_{ki}}{B_{ji}}\right)^{\frac{1-\eta+\eta b_i}{1-\eta+(1-d)\eta b_i}} x_i - \frac{x_i}{B_{ki}} + \left(\frac{B_{ki}}{B_{ji}}\right)^{\frac{db_i}{1-\eta+(1-d)\eta b_i}} l_{o_{ji}} \\
L_{o_i} &= \sum_{k=1}^{n_i} l_{o_{ki}} = \frac{\sum_{k=1}^{n_i} B_{ki}^{\frac{db_i}{1-\eta+(1-d)\eta b_i}}}{B_{ji}^{\frac{1-\eta+\eta b_i}{1-\eta+(1-d)\eta b_i}}} x_i - x_i \sum_{k=1}^{n_i} \frac{1}{B_{ki}} + \frac{l_{o_{ji}} \sum_{k=1}^{n_i} B_{ki}^{\frac{db_i}{1-\eta+(1-d)\eta b_i}}}{B_{ji}^{\frac{db_i}{1-\eta+(1-d)\eta b_i}}} \\
l_{o_{ji}} &= \frac{B_{ji}^{\frac{db_i}{1-\eta+(1-d)\eta b_i}}}{\sum_{k=1}^{n_i} B_{ki}^{\frac{db_i}{1-\eta+(1-d)\eta b_i}}} L_{o_i} + x_i\left(\frac{1}{B_{ji}} - \frac{B_{ji}^{\frac{db_i}{1-\eta+(1-d)\eta b_i}} \sum_{k=1}^{n_i} \frac{1}{B_{ki}}}{\sum_{k=1}^{n_i} B_{ki}^{\frac{db_i}{1-\eta+(1-d)\eta b_i}}}\right)
\end{aligned}
$$

On the other hand, since $\frac{l_{y_{ki}}}{l_{y_{ji}}} = \left(\frac{B_{ki}}{B_{ji}}\right)^{\frac{db_i}{1-\eta+(1-d)\eta b_i}}$,

$$
\begin{aligned}
\frac{L_{y_i}}{l_{y_{ji}}} &= \frac{\sum_{k=1}^{n_i} l_{y_{ki}}}{l_{y_{ji}}} = \frac{\sum_{k=1}^{n_i} B_{ki}^{\frac{db_i}{1-\eta+(1-d)\eta b_i}}}{B_{ji}^{\frac{db_i}{1-\eta+(1-d)\eta b_i}}} \\
l_{y_{ji}} &= \frac{B_{ji}^{\frac{db_i}{1-\eta+(1-d)\eta b_i}}}{\sum_{k=1}^{n_i} B_{ki}^{\frac{db_i}{1-\eta+(1-d)\eta b_i}}} L_{y_i}
\end{aligned}
$$

Using the above expressions for $l_{o_{ji}}$ and $l_{y_{ji}}$,

$$
\begin{aligned}
\frac{x_i + B_{ji} l_{o_{ji}}}{B_{ji} l_{y_{ji}}} &= \frac{\frac{B_{ji}^{\frac{1-\eta+\eta b_i}{1-\eta+(1-d)\eta b_i}} \sum_{k=1}^{n_i} \frac{1}{B_{ki}}}{\sum_{k=1}^{n_i} B_{ki}^{\frac{db_i}{1-\eta+(1-d)\eta b_i}}} x_i + \frac{B_{ji}^{\frac{1-\eta+\eta b_i}{1-\eta+(1-d)\eta b_i}}}{\sum_{k=1}^{n_i} B_{ki}^{\frac{db_i}{1-\eta+(1-d)\eta b_i}}} L_{o_i}}{\frac{B_{ji}^{\frac{1-\eta+\eta b_i}{1-\eta+(1-d)\eta b_i}}}{\sum_{k=1}^{n_i} B_{ki}^{\frac{db_i}{1-\eta+(1-d)\eta b_i}}} L_{y_i}} \\
&= \frac{x_i + \left(\sum_{k=1}^{n_i} B_{ki}^{-1}\right)^{-1} L_{o_i}}{\left(\sum_{k=1}^{n_i} B_{ki}^{-1}\right)^{-1} L_{y_i}} = \frac{n_i x_i + n_i \left(\sum_{k=1}^{n_i} B_{ki}^{-1}\right)^{-1} L_{o_i}}{n_i \left(\sum_{k=1}^{n_i} B_{ki}^{-1}\right)^{-1} L_{y_i}} = \frac{\overline{X}_i + B_i L_{o_i}}{B_i L_{y_i}}
\end{aligned}
$$

where $\overline{X}_i = n_i x_i,\ B_i = n_i \left(\sum_{k=1}^{n_i} B_{ki}^{-1}\right)^{-1}$. It is now easy to see that in the steady state, the Euler equation of intangible capital accumulation for any firm j in sector i is identical to the sector-level Euler equation in the baseline model. Therefore, the comparative statics results derived in section 3 still hold when there are multiple firms in a sector.

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