Rising Skill Premium?: The Roles of Capital-Skill Complementarity and Sectoral Shifts in a Two-Sector Economy*

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Abstract

Empirical studies report stark dispersion in skill-premium changes across economies over the past few decades. Structural models in early studies successfully replicate the increases in skill premiums in many economies, while some other cases with declined skill premium are yet to be explained. To this end, we develop a two-sector (i.e., manufacturing and non-manufacturing) general equilibrium model with skilled and unskilled labor, in which degrees of capital-skill complementarity differ across sectors. Based on the estimated structural parameters, we show that a decline in capital-skill complementarity in non-manufacturing sector can provide a consistent explanation for the Japanese data both at aggregate and industry levels: (i) the lower skill premium, (ii) the expansion of the sectoral wage gap, with a rise in manufacturing wage and a decline in non-manufacturing wage, and (iii) the rise of unskilled labor share in non-manufacturing sector.

Keywords: Capital-skill Complementarity; Skill Premium; Two-sector DSGE Model; Bayesian Estimation.

JEL Classification: E22, E24, J31;

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1 Introduction

While skill premium has generally been considered rising, a few economies experienced declines in skill premium in the past decade. Among others, this paper focuses on three notable observations in the Japanese labor market at the industry level. First, the skill premium, which is defined as a ratio of skilled wage to unskilled wage, started to decline since the late 1990s. Second, while manufacturing wage has kept increasing, non-manufacturing wage has declined substantially. Lastly, the input share of unskilled labor in non-manufacturing has markedly increased over time while, by contrast, it has remained stable in manufacturing. These changes observed in the Japanese economy are in sharp contrast to what we typically have seen in other economies. Understanding a main factor behind these differences has quite important policy implications for economic growth.

This paper studies a two-sector general equilibrium model with two types of labor, skilled and unskilled, and aims to account for the above-mentioned three observations in a neoclassical framework. In particular, we introduce capital-skill complementarity, such that production technology exhibits complementarity between skilled labor and physical capital stock as discussed in Krusell et al. (2000). We take our two-sector model to the data to estimate the key structural parameters of the model by using Bayesian methods. This is important for quantifying changes in the structure of the economy. Based on our model with the estimated structural parameter, we identify a main driving force behind the above-mentioned changes in the Japanese economy, through comparative statics exercises.

While aggregate hourly wage has started to decline since the mid-1990s, we observe stark difference in sectoral wages across the two sectors, i.e., manufacturing and non-manufacturing. We note that the hourly wage in manufacturing sector continues to rise over time. By contrast the hourly wage in non-manufacturing sector has declined since the mid-1990s. As a result. the sectoral wage gap, measured by relative wage, has expanded by about 17 percent since the mid-1990s. In a typical one-sector setup, we cannot illustrate this dispersion in sectoral wages. If there were no divergent patterns in sectoral wages, it would be possible to conclude that the declining aggregate wage reflects lower labor productivity. On the other hand, the skill premium, which is typically increasing in other advanced economies as well as emerging countries, has decreased by about 7 percent on average. In one-sector models, the reduction in the skill premium can be simply attributable to skill-biased technological changes. However, with the divergent patterns in sectoral wages, skill-biased technological changes cannot be an explanation for the observed changes, because they affect both manufacturing and non-manufacturing proportionally.

In this paper, we show that changes in capital-skill complementarity in non-manufacturing sector can explain the stylized facts. This means that we primarily focus on the demand side of the labor market. Even though we introduce skilled and unskilled workers, we abstract from a labor-supply-side story.[1] We just take the existence of the two types of labor as given and assume that the household does not care which sector he/she works at. The two sectors hire both skilled and unskilled workers. Depending on the degree of capital-skill complementarity, firms choose a different mix of skilled and unskilled workers in terms hiring.

Based on the estimated structural parameters, we find that a decline in the degree of capital-skill complementarity in non-manufacturing sector can account for the observed decline in the skill premium. Specifically, lower capital-skill complementarity arising from a reduction in the elasticity of substitution between capital and unskilled labor in non-manufacturing industry provides the consistent explanation for the observed changes in the skill premium and sectoral wages as well as the increased share of unskilled labor in the non-manufacturing sector.

We believe that the lower capital-skill complementarity is consistent with what has been underway in the Japanese economy since the mid-1990s. In our two-sector model, we can interpret a drop in the elasticity of substitution between capital and unskilled labor as a result of the ongoing expansion of unskilled labor intensive services sector, such as food services and nursing care. Even though we cannot address this compositional effect within non-manufacturing industry in this model, the increasing importance of these industries relative to the traditional non-manufacturing industries is reflected in the lower elasticity of substitution between capital and unskilled labor.

The idea of capital-skill complementarity is not new. Griliches (1969) first hypothesizes that skill or education is more complementary with physical capital than unskilled labor. Recently, Krusell et al. (2000) revive the idea of capital-skill complementarity. They use capital-skill complementarity to account for the observed increases in the skill premium in the US economy at the aggregate level. Although the increased skill premium has typically been attributed to unobserved skill-biased technological changes,[2] they argue that capital-skill complementarity helps explain observed changes in the skill premium. Polgreen and Silos (2007) re-examine findings of Krusell et al. (2000). They assure the existence of capital-skill complementarity. However, they also find that other results in Krusell et al. (2000) were sensitive to the data used. Maliar and Maliar (2011) construct a general equilibrium version of Krusell et al. (2000), together with additional driving forces. They derive restrictions that make the model consistent with balanced growth.

Most of these studies focus on the long-run implications of capital-skill complementarity. Lindquist (2004) looks at a cyclical property of capital-skill complementarity. His finding suggests that capital-skill complementarity is an important factor in explaining the skill

[1] For example, Kawaguchi and Mori (2008) seek to offer some evidence for a labor-supply-side story to explain changes in the wage gap between college and high school graduates. The skill premium we will look at is different from the college premium they analyzed. In this sense, our story does not conflict with theirs.

[2] There exists a vast literature in the skill-biased technological change. See, for example, Acemoglu (2002).

premium over the business cycle. In terms of aggregate production technology, however, Balleer and van Rens (2013) reach the opposite conclusion. They construct a quarterly skill premium in the US economy using the Current Population Survey and estimate responses of the economy to various technology shocks using a structural vector autoregression. In particular, they find that the skill premium responds negatively to the investment-specific technology shock. Their finding rejects the possibility of capital-skill complementarity and favors for capital-skill substitutability in the aggregate production technology.

Autor and Dorn (2013) study a rise of low-skill service jobs and the employment and wage polarizations of the US economy. Their setup is similar to ours with more differentiated labor types (manual, routine, and abstract labor). Their model predicts that under certain conditions, which are involved with a preference parameter and the elasticity of substitution between routine labor and computer capital (skilled labor and physical capital stock in our model), routine-tasks industries reallocate low-skilled labor into services and receive inflows of skilled labor.

Capital-skill complementarity becomes also important in the international trade literature. Parro (2013) develops a general equilibrium trade model with capital goods trade and capital-skill complementarity. In this setup, he shows that there are two possibilities that increase the skill premium. A technical change causes a reduction in the relative price of capital, which in turn increases the skill premium. This is true even in a closed economy. In addition, with capital goods trade, a decline in trade costs also decreases the price of capital goods, inducing more trade in capital goods. As a result, the productivity of skilled labor and the skill premium increase when capital-skill complementarity exists. This result has an important welfare implication for the Japanese economy. If capital-skill complementarity weakens, it becomes more difficult for the Japanese economy to enjoy gains from trade (through cheaper capital goods with reduced transportation costs).

In terms of changes in sectoral allocation of labor, Ngai and Pissarides (2007) offer an alternative explanation. They show that as long as goods and services are complements, labor flows into a sector with lower TFP growth. Marquis and Trehan (2010) apply this idea to explain sectoral dynamics in the US economy. They find that the elasticity of substitution between goods and services is zero or close to it, and thus labor flows from manufacturing to services. However, our estimation results suggest that the elasticity of substitution between goods and services are not close to zero. Rather it is significantly greater than unity.

Aside from the concept of capital-skill complementarity and two types of labor, this paper is related to Iacoviello et al. (2011). They construct and estimate a two-sector DSGE model, using Bayesian methods. In line with our model, they make a clear distinction between goods and services. Their model features detailed structure of inventories in order to capture business cycle propagation mechanism. Two sectors (goods-producing and services-producing sectors) are differentiated by whether they hold inventories or not. This type of distinction is not included in our paper. Instead, two sectors (i.e., goods and services) are different in our setup in terms of production technology, especially the degree of capital-skill complementarity.

The rest of the paper is organized as follows. Section 2 presents the stylized facts that we would like to explain in this paper. Section 3 presents a two-sector neo-classical model with two types of labor. In Section 4, we use Bayesian methods to estimate model parameters that are important for explaining the stylized facts. We then use the estimated parameters to conducts comparative statics exercises in Section 5. Finally, Section 6 concludes.

2 Stylized Facts

In this section, we will present stylized facts about the labor market in Japan that we would like to explain in this paper. We will focus on the following three facts.

Fact 1 The skill premium has started to decline (at least over last two decades, 2.5 $\rightarrow$ 2.3).

Fact 2 While wage in manufacturing sector has been increasing over time, that in non-manufacturing has started to decrease since the mid 1990s. As a result, the manufacturing to non-manufacturing wage ratio has increased drastically.

Fact 3 While the importance of part-time workers in manufacturing industry has stayed unchanged, the increasing fraction of total hours worked by part-time workers in non-manufacturing industry has increased since the mid 1990s.

One important characteristic in the labor market is the distinction between skilled and unskilled workers. Now let us look at how the ratio of skilled wage to unskilled wage, so-called the skill premium, has evolved over time. Figure 1 illustrates skill premiums in manufacturing and non-manufacturing industries. Unlike other economies, over the last two decades, the skill premium has not increased. It has been declining. From 1993 to 2012, the skill premiums in manufacturing and non-manufacturing declined by 6.5% and 7.5%, respectively. Alternatively, we can look at the education-based measure. Parro (2013) uses the college/high-school graduates wage ratio and finds that the skill premium in Japan declined by 3.4% from 1990 to 2005. This downward trend contrasts with other countries. For example, the skill premium in Germany increased by 14.4% over the same period. In the US, Parro (2013) finds that the skill premium based on production/non-production workers wage ratio rises by 3.1% from 1990 to 2007. We do not see this downward trend in the skill premium in many countries. In fact, among 28 countries he looks at, we observe declines in the skill premium only in eight countries. A typical argument suggests that demand for unskilled workers should increase in advanced economies through trade with emerging economies or off-shoring. As a result, it would be natural to expect an increasing trend in

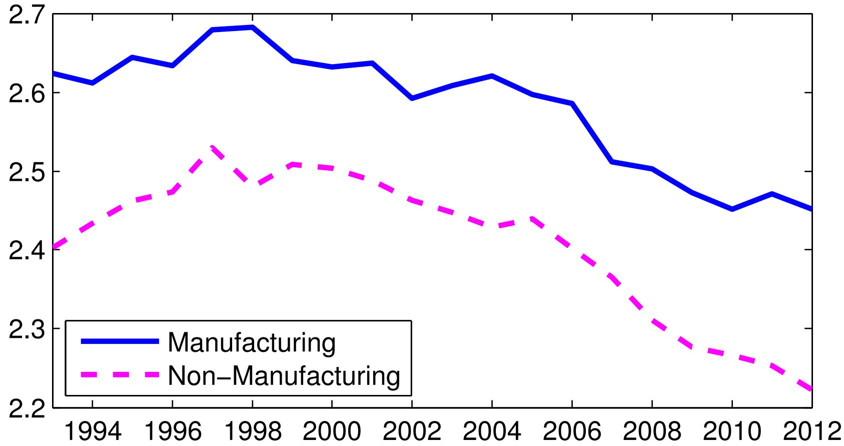


Figure 1: Skill Premium

Note: The skill premium is defined as a ratio of nominal hourly wage paid to full-time workers to that of part-time workers. We take the data from the Monthly Labour Survey of the Ministry of Health, Labour, and Welfare, and we look at the data on establishments with five or more employees. Non-manufacturing excludes agriculture, forestry, fishing, and public administration sectors.

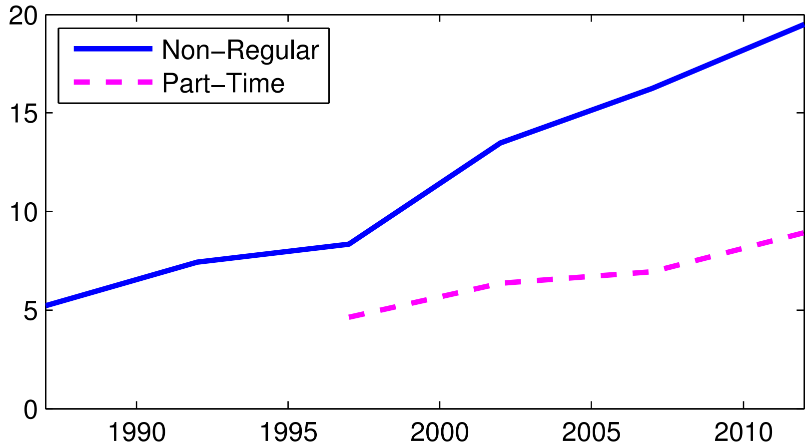


Figure 2: Fraction of Non-Regular/Part-Time Jobs in College-Graduate Employments (%)

Note: Data are taken from Employment Status Survey conducted by the Statistics Bureau of Japan in 1987, 1992, 1997, 2002, 2007, and 2012. We calculate fraction of non-regular workers in college-graduate employments (excluding executives) and that of part-time workers (including temporary workers). For 1987 and 1992, we do not know the number of executives. We assume that 10% of total college-graduate employments are executives. 10% is very close to the average fraction in other years.

the skill premium. Since the literature has focused on how to explain this upward trend, it is important to investigate why the skill premium in Japan and also in other countries has declined (or even not increasing).

In this paper, we view full-time workers as skilled labor, and we use part-time workers, whose scheduled work hours are shorter than regular employees of the same business establishment, as a proxy for unskilled labor. We admit that this is not an ideal measure to distinguish skilled and unskilled workers. The college/high-school wage ratio, which is sometimes called the college premium, is an alternative measure for the skill premium. The skill premium based on the level of education gives us qualitatively the same result as the one based on full-time/part-time workers. However, we argue that part-time workers are more suitable for the notion of unskilled workers because tasks performed by part-time workers are limited to less skill-intensive ones. Furthermore, we can have longer time-series data for part-time workers, compared with the education based labor inputs. This is advantageous in out estimation. Practically, we believe that using part-time workers as a proxy for unskilled workers is the best we can do at the industry level, given the availability of data.

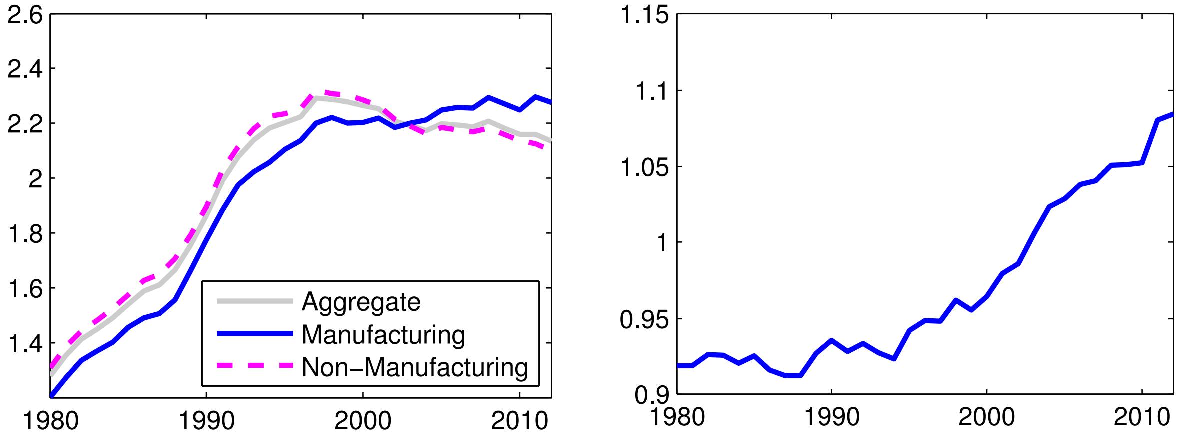
Figure 2 provides some justification for not using college/high-school graduates to classify skilled and unskilled workers. It shows the fraction of college-graduate workers who are classified as non-regular workers (solid line) or part-time (including temporary) workers (dashed line). It is clear that there is increasing tendency for college graduates working at less skill demanding jobs. These non-regular jobs or part-time jobs usually involve routine tasks and do not pay well. If we use college/high-school graduates as proxies for skilled/unskilled workers, we may overestimate the size of skill premium. We acknowledge that regular workers include those who may not be skilled. However, we believe that treating part-time workers as a proxy for unskilled workers is more suitable in our context, together with data availability.

Figure 3a presents nominal hourly wage at the aggregate level, as well as the sectoral data.[3] Wages in manufacturing and non-manufacturing sectors were increasing until the mid 1990s. However, we can observe a sudden change in this pattern. While manufacturing wage keeps increasing (despite at somewhat slower pace), non-manufacturing wage has started to decline. Since the non-manufacturing share is about 75%, the drop in non-manufacturing wage keeps dragging the aggregate hourly wage down. We call this wage deflation.

Figure 3b shows the ratio of manufacturing wage to non-manufacturing wage. It is clear that while the ratio was stable until the mid 1990s, it started to rise drastically afterwards. If the wage deflation were just accompanied by deflation in the price level, we would not observe this divergent pattern in the sectoral wages. In this sense, it is very important to look at the sectoral data to understand the nature of aggregate wage deflation. The gap has been widened by about 17%.

Figure 4 reports the unskilled labor shares in manufacturing and non-manufacturing sectors. Again, we use hours worked by part-time workers as a proxy for unskilled labor. While the share of unskilled workers in manufacturing sector remains relatively unchanged, that in non-manufacturing industry has been increasing over time. Krusell et al. (2000) report that the labor input ratio of skilled to unskilled has been increasing in the US data since the

[3]See the note to Figure 3 for description about the data and definition of manufacturing and non-manufacturing industries.



(a) Nominal Wage (1,000 Yen)

(b) Manufacturing to Non-Manufacturing Wage Ratio

Figure 3: Nominal Wage Data

Note: We calculate the nominal hourly wage by dividing the total monthly wage bill (including overtime and bonuses) by the total hours worked in the month (including overtime hours). As long as it is available, we use the data on establishments with five or more employees. Prior to 1989, however, we extrapolate them by using the data on establishments with 30 or more employees. We exclude agriculture, forestry, fishing, and public administration from the aggregate economy. Then it is divided into manufacturing and non-manufacturing. The data are obtained from the Labor Force Survey conducted by the Statistics Bureau, the Ministry of Internal Affairs and Communications, and from the Monthly Labor Survey of the Ministry of Health, Labor and Welfare.

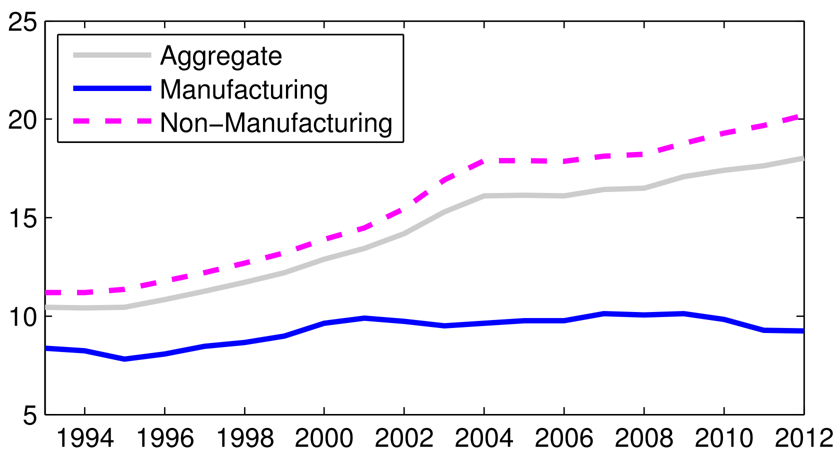


Figure 4: Fraction of Total Hours Worked by Part-time Workers (%)

Note: The data is taken from the Monthly Labour Survey of the Ministry of Health, Labour, and Welfare, and we look at the data on establishments with five or more employees. Non-manufacturing excludes agriculture, forestry, fishing, and public administration. We divide the total hours worked by part-time workers by those by regular employees (full-time and part-time workers).

1960s. Meanwhile, the skill premium has increased drastically, especially from 1980s to 1990s. These two are the opposite of what we see in the Japanese economy.

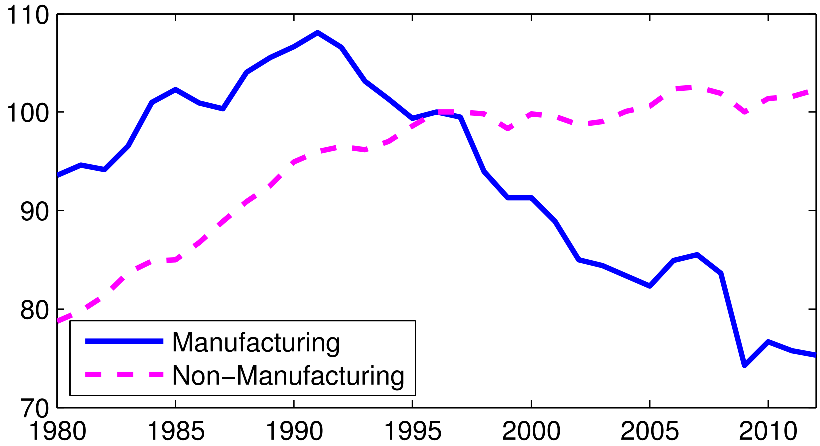


Figure 5: Sectoral Labor Inputs (1996 = 100)

Note: We define labor inputs as the product of the total hours worked per regular employee and the number of employees. The total hours worked are obtained from the Monthly Labor Survey of the Ministry of Health, Labor, and Welfare. We take the total number of employees from the Labor Force Survey conducted by the Statistics Bureau, the Ministry of Internal Affairs and Communications. As long as it is available, we use the data on establishments with five or more employees. Prior to 1989, we extrapolate them by using the data on establishments with 30 or more employees.

Lastly, in addition to the three stylized facts, let us compare how sectoral labor inputs have been changing over time as a reference. Figure 5 compares total hours worked in manufacturing and non-manufacturing industries (normalized with 1996 = 100). While manufacturing labor has been declining over time, non-manufacturing labor has been increasing. This is a typical pattern observed in many countries.

In the next section, we will present a model that can explain these three stylized facts in the Japanese economy.

3 The Model

The economy consists of a infinitely-lived representative household and two sectors, manufacturing (sector 1) and non-manufacturing (or services, sector 2). There are two types of labor that the household supplies, skilled and unskilled labor. Output from the manufacturing sector will be consumed and invested. Capital stock is sector-specific and it is immobile between two sectors.

3.1 Household

The representative household chooses consumption of goods ($C_{1,t}$) and services ($C_{2,t}$), labor supply of skilled (S_t) and unskilled (U_t), investment in two sectors ($I_{1,t}$ and $I_{2,t}$) to maximize the discounted expected life-time utility

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t u(C_t, H_t), \tag{1}$$

subject to the budget constraint and the law of motion for capital stock in each sector. Here β denotes the subjective discount factor. The budget constraint in real terms is given by

$$C_{1,t} + p_t C_{2,t} + I_{1,t} + I_{2,t} \leq r_{1,t} K_{1,t} + r_{2,t} K_{2,t} + w_{s,t} S_t + w_{u,t} U_t, \tag{2}$$

where $p_t \equiv P_{2,t}/P_{1,t}$, $r_{1,t} \equiv R_{1,t}/P_{1,t}$, $r_{1,t} \equiv R_{2,t}/P_{1,t}$, $w_{s,t} \equiv W_{s,t}/P_{1,t}$, $w_{u,t} \equiv W_{u,t}/P_{1,t}$. $P_{1,t}$ represents a manufacturing goods price and $P_{2,t}$ is a price for non-manufacturing goods. $R_{1,t}$ and $R_{2,t}$ are the rental rates of capital stock. $W_{s,t}$ and $W_{u,t}$ denote nominal wages for skilled and unskilled labor, respectively. The law of motion for capital stock in each sector $j = 1, 2$ is subject to investment adjustment costs $\Phi(\cdot)$ and given by

$$K_{j,t+1} = I_{j,t} \left\{ 1 - \Phi\left(\frac{I_{j,t}}{I_{j,t-1}} \right) \right\} + (1 - \delta) K_{j,t}. \tag{3}$$

Following Horvath (2000), we assume that the aggregate labor index takes the following form:

$$H_t = \left[(S_t)^{\frac{\theta+1}{\theta}} + (U_t)^{\frac{\theta+1}{\theta}} \right]^{\frac{\theta}{\theta+1}}, \tag{4}$$

where S_t and U_t represent skilled and unskilled labor, respectively. θ controls the elasticity of substitution between skilled and unskilled jobs. As $\theta \to \infty$, skilled and unskilled jobs become perfect substitutes. Thus, if skilled job pays higher wage, the household just allocates all of labor supply to the high-paying skilled job. On the other hand, when $\theta \to 0$, there is no way to change the composition of two types of jobs, so that skilled and unskilled jobs become perfect complements. In a realistic case, where $0 < \theta < \infty$, the household prefers having diversity of labor. In this way, we can have a situation, where the household can supply both types of labor, even when nominal wages offered to skilled and unskilled are different. We believe that this assumption is reasonable. This is the most parsimonious way to introduce skilled and unskilled labor into the representative agent framework.[4] For example, Kondo and Naganuma (2013) find that skill difference is an important factor affecting workers' inter-industry flow in Japan. This specification may be viewed as a parsimonious way of describing the job polarization.

The composite consumption good C_t, which aggregates manufacturing goods and ser-

[4]Alternatively, we could introduce sector-specific skills, such as skilled and unskilled workers in manufacturing and those in non-manufacturing, and corresponding sector-specific skill-biased technology shocks. However, the ratio of skilled wages paid in manufacturing and non-manufacturing has been stable. The same applies to the unskilled wages. Thus, we believe that there is no harm to assume that the labor market is not segmented across sectors.

vices, is defined similarly as

$$C_t = \left[\gamma \left(C_{1,t}\right)^{\frac{\kappa-1}{\kappa}} + (1-\gamma)\left(C_{2,t}\right)^{\frac{\kappa-1}{\kappa}} \right]^{\frac{\kappa}{\kappa-1}}, \tag{5}$$

where $\gamma \in [0,1]$ is a share of a manufacturing good and κ is the elasticity of substitution between manufacturing goods and services. As $\kappa \to 1$, $C_t = C_{1,t}^{\gamma} C_{2,t}^{1-\gamma}$. As $\kappa \to \infty$, $C_t = \gamma C_{1,t} + (1-\gamma) C_{2,t}$.

For simplicity, we assume separability between the aggregate consumption and labor. A parametric form of the household preferences is given by

$$u(C_t, H_t) = \log(C_t) - \varphi \frac{\eta}{1+\eta} H_t^{\frac{\eta+1}{\eta}}, \tag{6}$$

where η is the Frisch elasticity of aggregate labor supply.

3.2 Firms

There are two types of firms in the economy, manufacturing (sector 1) and non-manufacturing (or services, sector 2). A representative firm in each sector takes factor prices as given and maximizes its profits period by period.

We assume that production technology exhibits capital-skill complementarity as in Krusell et al. (2000). For each sector $j = 1, 2$, sectoral output $Y_{j,t}$ is produced from the following technology

$$Y_{j,t} = A_{j,t} \left[\mu_j (\psi_{u,t} U_{j,t})^{\sigma_j} + (1-\mu_j) \left\{ \lambda_j (K_{j,t})^{\rho_j} + (1-\lambda_j)(\psi_{s,t} S_{j,t})^{\rho_j} \right\}^{\sigma_j/\rho_j} \right]^{1/\sigma_j}, \tag{7}$$

where $A_{j,t}$ represents sectoral productivity, and $\psi_{s,t}$ and $\psi_{u,t}$ measure quality of skilled and unskilled labor, respectively. μ_j and λ_j control factor shares of unskilled labor and capital, respectively.

We assume exogenous processes that drive sectoral productivity, and skilled and unskilled labor efficiency as follows:

$$\log(A_{j,t}) = (1-\rho_{A_j}) \log(A_j) + \rho_{A_j} \log(A_{j,t-1}) + \varepsilon_{j,t}, \tag{8}$$

$$\log(\psi_{l,t}) = (1-\rho_{\psi_l}) \log(\psi_l) + \rho_{\psi_l} \log(\psi_{l,t-1}) + \eta_{l,t}, \tag{9}$$

where $\varepsilon_{j,t} \sim N(0, \sigma^2_{A_j})$ and $\eta_{l,t} \sim N(0,, \sigma^2_{\psi_l})$ for $j = 1, 2$ and for $l = s, u$. Sectoral productivity and labor efficiency are assumed to be stationary with $|\rho_{A_j}| < 1$ for $j = 1, 2$ and $|\rho_{\psi_l}| < 1$ for $l = s, u$. This assumption excludes that differences in productivity growth rate drives sectoral shifts.

The elasticity of substitution between capital and unskilled labor is given by $\dfrac{1}{1-\sigma_j}$.

Similarly, the elasticity of substitution between capital and skilled labor is $\dfrac{1}{1-\rho_j}$. As shown in Krusell et al. (2000), when $\sigma_j > \rho_j$, there is capital-skill complementarity. When $\sigma_j \to 0$ and $\rho_j \to 0$, the typical Cobb-Douglas production function emerges as a special case:

$$Y_{j,t} = A_{j,t}(K_{j,t})^{(1-\mu_j)\lambda_j}(\psi_{s,t}S_{j,t})^{(1-\mu_j)(1-\lambda_j)}(\psi_{u,t}U_{j,t})^{\mu_j}. \tag{10}$$

3.3 The Rest of the Model

To clear labor markets for skilled and unskilled workers, goods market, and services market, we have the following market clearing conditions.

$$S_t = S_{1,t} + S_{2,t} \tag{11}$$

$$U_t = U_{1,t} + U_{2,t} \tag{12}$$

$$Y_{1,t} = C_{1,t} + I_{1,t} + I_{2,t} \tag{13}$$

$$Y_{2,t} = C_{2,t} \tag{14}$$

We construct the sectoral wage for $j = 1, 2$ by

$$w_{j,t} = (1 - \tau_{j,t})w_{s,t} + \tau_{j,t}w_{u,t}, \tag{15}$$

where $\tau_{j,t} = \frac{U_{j,t}}{S_{j,t}+U_{j,t}}$.

4 Estimation

Now we will take our model to the data to estimate key model parameters that determine the size of capital-skill complementarity (σ's and ρ's), together with other structural parameters. To this end, we estimate the model structurally by using a Bayesian approach. In order to improve fit of the model, we will augment our model presented in Section 3 by introducing sector-specific investment-specific technology shocks and skill-specific wage markup shocks. All of these shocks are assumed to follow standard AR(1) specifications. By taking our model to the data, we can evaluate what is the true determinant of the observed changes in the Japanese economy through the estimated structural parameters.[5]

[5]Since our model is a closed-economy model, we exclude a possible channel through international trade. The prediction from the Stolper-Samuelson theorem is a reduction in the skill premium in countries where unskilled labor is abundant. It is difficult to say that Japan is a unskilled-labor-abundant country, relative to other countries. Thus, there is no harm to exclude the international trade channel.

4.1 Data

In order to take advantage of our two-sector setup, we will utilize quarterly disaggregated data. We assume that output from manufacturing sector is used for durable good purchases, business fixed investment, and residential investment. Similarly, non-manufacturing output is used for non-durable goods and services. It is quite difficult to have a clear distinction between skilled and unskilled labor, especially at the quarterly frequency for sufficiently long time periods. We will construct our measures for hours worked for skilled and unskilled (proxied by part-time workers) labor. Appendix explains the detailed procedures of the data construction. Our sample starts from 1975:Q1 and ends at 1995:Q4. Our purpose is to configure our model parameters, so that it well represents the Japanese economy before the change we observe in the 1990s. This motivates us to pick 1995:Q4, which roughly corresponds to the timing we start to observe the changes in the labor market depicted in Figure 3, as the end of our sample.

We will use the following data to estimate the model: the growth rate of manufacturing output ($dy_{1,t}$), the growth rate of non-manufacturing output ($dy_{2,t}$), the growth rate of total hours worked by full-time workers (ds_t), the growth rate of total hours worked by part-time workers (du_t), the growth rate of manufacturing wage ($dw_{1,t}$), the growth rate of non-manufacturing wage ($dw_{2,t}$), and the inflation rate of the relative price between manufacturing and non-manufacturing (dp_t).

We solve the log-linearized system of equations that are presented in the Appendix A to get a state-space representation of the solution. It is then used to evaluate the log-likelihood function with the Kalman filter. Model variables that are expressed in terms of deviations from the steady state are linked to the data (all observable variables are demeaned) through the observation equation as follows.

$$dy_{1,t} = \hat{y}_{1,t} - \hat{y}_{1,t-1} \tag{16}$$

$$dy_{2,t} = \hat{y}_{2,t} - \hat{y}_{2,t-1} \tag{17}$$

$$ds_t = \hat{s}_t - \hat{s}_{t-1} \tag{18}$$

$$du_t = \hat{u}_t - \hat{u}_{t-1} \tag{19}$$

$$dw_{1,t} = \hat{w}_{1,t} - \hat{w}_{1,t-1} \tag{20}$$

$$dw_{2,t} = \hat{w}_{2,t} - \hat{w}_{2,t-1} \tag{21}$$

$$dp_t = \hat{p}_t - \hat{p}_{t-1} \tag{22}$$

4.2 Prior Distributions

We fix some parameter values and impose the steady-state ratios in the estimation in order to maintain consistency with the reality. They are summarized in Table 1. We set the discount factor (β) to be 0.995 and the depreciation rate (δ) to be 0.025. Manufacturing

Table 1: List of Parameter Values Imposed

Discount factor	$\beta = 0.995$
Depreciation rate	$\delta = 0.025$
Goods expenditure share	$\omega_1 = 0.35$
Skill premium	$\pi = 2.5$
Skilled-Unskilled ratio in sector 1	$\frac{S_1}{U_1} = 11.31$
Skilled-Unskilled ratio in sector 2	$\frac{S_2}{U_2} = 7.89$
Capital cost share in sector 1	$\alpha_{k_1} = 1 - 0.517$
Capital cost share in sector 2	$\alpha_{k_2} = 1 - 0.536$
Fraction of skilled in sector 1	$f_s = \frac{S_1}{S_1+S_2} = 0.3$
Fraction of unskilled in sector 1	$f_u = f_s \left(\frac{w_s}{w_u}\right)^{\theta} \left(\frac{S_1}{U_1}\right)^{-1}$
Share of skilled workers	$\omega_s = \frac{\pi^{\theta+1}}{\pi^{\theta+1}+1}$
Share of unskilled in sector 1	$\omega_{u_1} = (1 - \alpha_{k_1})\left(\frac{w_s}{w_u}\frac{S_1}{U_1} + 1\right)^{-1}$
Share of unskilled in sector 2	$\omega_{u_2} = (1 - \alpha_{k_2})\left(\frac{w_s}{w_u}\frac{S_2}{U_2} + 1\right)^{-1}$
Share of capital in sector 1	$\omega_{k_1} = \frac{\alpha_{k_1}}{(1-\omega_{u_1})}$
Share of capital in sector 2	$\omega_{k_2} = \frac{\alpha_{k_2}}{(1-\omega_{u_2})}$
Consumption share of goods	$\omega_c = (1 - \omega_{i_1})\left(1 + \frac{\delta\alpha_{k_2}}{r_2}\frac{(1-\omega_1)}{\omega_1}\right)^{-1}$
Investment share of goods in sector 1	$\omega_{i_1} = \frac{\delta\alpha_{k_1}}{r_1}$

goods expenditure share (ω_1) is assumed to be 0.35. We assume that the steady-state skill premium $\frac{w_s}{w_u}$ is 2.5, which is consistent with the values in the early 1990s.[6] We set the skilled-unskilled ratio in manufacturing ($\frac{S_1}{U_1}$) to be 11.31 and that in non-manufacturing ($\frac{S_2}{U_2}$) to be 7.89. These values are based on the average fraction of part-time workers to full-time workers over 1993–1995.[7] Since the average labor income shares in manufacturing and non-manufacturing from 1980 to 1995 are 51.7% and 53.6%, respectively, we set the capital cost share parameters $\alpha_{k_1} = 0.483$ and $\alpha_{k_2} = 0.464$. Finally, we assume that the manufacturing share of skilled workers $\frac{S_1}{S_1+S_2}$ to be 0.3. Through the steady-state relationship, we can infer other steady-state ratios that are summarized in Table 1.

Table 2 summarizes the model parameters to be estimated, together with the associated prior distributions. There are a couple of things we need to discuss. We use a Gamma distribution with mean 1.143 and standard deviation of 0.4 as a prior distribution for κ. This will give us its mode located at 1, which corresponds to Cobb-Douglas preferences over C_1 and C_2. Prior probability of $\kappa < 1$ is 40%. We think that this is much more agnostic prior than the one used in Iacoviello et al. (2011), for example. Whether the value of κ is greater or less than unity is crucial for whether the data support the story of Ngai and Pissarides (2007) or not.

[6] We do not have good data on the size of skill premium in the early periods.

[7] Again, we do not have good data on the ratio of skilled to unskilled workers at the sectoral level in the earlier periods.

Table 2: Prior Distributions

Parameter		Dist.	Prior Mean	Std Dev
κ	Elasticity of substitution between goods and services	G	1.143	0.4
$\frac{1}{\eta}$	Inverse Frisch labor supply elasticity	N	2	0.75
σ_1	Controlling the elasticity of substitution between K_1 and U_1	B	0.2	0.2
σ_2	Controlling the elasticity of substitution between K_2 and U_2	B	0.2	0.2
α_1	Controlling capital-skill complementarity in sector 1	G	0.5	0.5
α_2	Controlling capital-skill complementarity in sector 2	G	0.5	0.5
φ	Investment adjustment cost parameter	G	4	1
ρ_{a_1}	Persistence of TFP in sector 1	B	0.75	0.1
ρ_{a_2}	Persistence of TFP in sector 2	B	0.75	0.1
ρ_{ψ_s}	Persistence of skilled-specific shock	B	0.75	0.1
ρ_{ψ_u}	Persistence of unskilled-specific shock	B	0.75	0.1
ρ_{ξ_1}	Persistence of investment-specific shock in sector 1	B	0.75	0.1
ρ_{ξ_2}	Persistence of investment-specific shock in sector 2	B	0.75	0.1
ρ_{μ_s}	Persistence of wage markup shock for skilled	B	0.75	0.1
ρ_{μ_u}	Persistence of wage markup shock for unskilled	B	0.75	0.1
σ_{a_1}	Std Dev of TFP shock in sector 1	IG	0.025	∞
σ_{a_2}	Std Dev of TFP shock in sector 2	IG	0.025	∞
σ_{ψ_s}	Std Dev of skilled-specific shock	IG	0.025	∞
σ_{ψ_u}	Std Dev of unskilled-specific shock	IG	0.025	∞
σ_{ξ_1}	Std Dev of investment-specific shock in sector 1	IG	0.025	∞
σ_{ξ_2}	Std Dev of investment-specific shock in sector 2	IG	0.025	∞
σ_{μ_s}	Std Dev of wage markup shock for skilled	IG	0.025	∞
σ_{μ_u}	Std Dev of wage markup shock for unskilled	IG	0.025	∞

Note: N, B, G, IG, and U stand for Normal, Beta, Gamma, Inverse Gamma, and Uniform distributions, respectively.

We assume that σ_j for $j = 1, 2$ is from a Beta distribution with mean and standard deviation of 0.2. Our underlying assumption is that the elasticity of substitution between capital and unskilled labor is greater than or equal to unity. We define $\alpha_j \equiv \sigma_j - \rho_j$, which controls the degree of capital-skill complementarity. We use a Gamma distribution with mean 0.5 and standard deviation 0.5 for a prior distribution for α_j. This reflects our prior belief that there exists capital-skill complementarity. We also allow for a possibility of no capital-skill complementarity since the support of α_j includes zero.

The rest of prior distributions are standard. The prior for the inverse Frisch labor supply elasticity is the same as in Sugo and Ueda (2008). It is Normally distributed and centered at 2 with standard deviation of 0.75. The prior for investment cost parameter φ is a Gamma distribution with mean 4 and standard deviation of 1. This is a widely used prior for the investment adjustment cost parameter. Prior distributions for the persistence parameters are all set to Beta distributions with mean 0.75 and standard deviations of 0.1. We assume that prior for the standard deviations of the structural shocks are all Inverse Gamma distributions with mean 0.025. These choices about prior distributions of the structural shocks are based

Table 3: Posterior Distributions

Parameter		Posterior Distribution Mean	90% Interval	
κ	Elasticity of substitution between goods and services	4.2085	3.4174	5.0088
$\frac{1}{\eta}$	Inverse Frisch labor supply elasticity	1.9680	1.4054	2.5348
σ_1	Controlling the elasticity of substitution between K_1 and U_1	0.5674	0.4940	0.6411
σ_2	Controlling the elasticity of substitution between K_2 and U_2	0.0018	0.0000	0.0046
α_1	Controlling capital-skill complementarity in sector 1	4.7185	2.8622	6.4955
α_2	Controlling capital-skill complementarity in sector 2	0.5294	0.4042	0.6520
φ	Investment adjustment cost parameter	3.7687	2.2235	5.2887
ρ_{a_1}	Persistence of TFP in sector 1	0.6990	0.5675	0.8292
ρ_{a_2}	Persistence of TFP in sector 2	0.9448	0.9138	0.9769
ρ_{ψ_s}	Persistence of skilled-specific shock	0.6969	0.5597	0.8201
ρ_{ψ_u}	Persistence of unskilled-specific shock	0.7868	0.6768	0.9041
ρ_{ξ_1}	Persistence of investment-specific shock in sector 1	0.6916	0.4357	0.9157
ρ_{ξ_2}	Persistence of investment-specific shock in sector 2	0.8188	0.6687	0.9667
ρ_{μ_s}	Persistence of wage markup shock for skilled	0.9561	0.9270	0.9847
ρ_{μ_u}	Persistence of wage markup shock for unskilled	0.8059	0.7161	0.8948
σ_{a_1}	Std Dev of TFP shock in sector 1	0.0244	0.0206	0.0282
σ_{a_2}	Std Dev of TFP shock in sector 2	0.0108	0.0091	0.0123
σ_{ψ_s}	Std Dev of skilled-specific shock	0.0347	0.0284	0.0412
σ_{ψ_u}	Std Dev of unskilled-specific shock	0.2316	0.1730	0.2907
σ_{ξ_1}	Std Dev of investment-specific shock in sector 1	0.0454	0.0061	0.1225
σ_{ξ_2}	Std Dev of investment-specific shock in sector 2	0.0890	0.0203	0.1568
σ_{μ_s}	Std Dev of wage markup shock for skilled	0.0289	0.0241	0.0340
σ_{μ_u}	Std Dev of wage markup shock for unskilled	0.0625	0.0547	0.0707
	Log Marginal Density	1514.92		

Note: Posterior distributions are generated from 300,000 Metropolis-Hastings draws. We discard the first 10% of draws as a burn-in period. We use the modified Harmonic mean estimator of Geweke (1999) to obtain the log marginal density.

on Iacoviello et al. (2011).

4.3 Results

Table 3 summarizes the posterior distributions of parameters estimated, which are generated from 300,000 Metropolis-Hastings draws (the first 30,000 draws are discarded as burn-in). We set the scaling parameter in the Metropolis-Hastings algorithm, such that the average acceptance rate becomes about 30%. It is worth emphasizing a couple of things about our estimation results.

First, the elasticity of substitution between capital and unskilled labor differs substantially between manufacturing and non-manufacturing. On the one hand, the posterior mean of σ_1 is quite high with 0.5674. The implied elasticity of substitution between capital and unskilled labor in manufacturing is 2.3116. It is much higher than the estimate in Krusell et al. (2000), which is obtained from the US aggregate data (1.67). On the other hand, the posterior mean of σ_2 is quite small. It is 0.0018. Indeed, the 90 percent probability interval contains zero. The implied elasticity of substitution is virtually unity (1.0018).

Second, the degree of capital-skill complementarity is quite different between manufacturing and non-manufacturing. The posterior mean of α_1 is 4.7185, suggesting that there exists strong capital-skill complementarity in manufacturing. This implies that the estimated value of ρ_1 is -4.1511. The implied elasticity of substitution between capital and skilled labor in manufacturing is 0.1941, which is quite low. In fact, this is far smaller than the estimate in Krusell et al. (2000), which is 0.67. Although we can exclude the possibility of no capital-skill complementarity in non-manufacturing, the degree of capital-skill complementarity in non-manufacturing is not so strong. In fact, the posterior mean of α_2 is 0.5294, suggesting that $\rho_2 = -0.5276$. The 90 percent probability interval ranges from 0.4042 to 0.6520. The implied elasticity of substitution between capital and skilled labor in non-manufacturing is 0.6546, which is higher than in manufacturing, but is lower than the Cobb-Douglas case.

Third, the posterior mean of κ is 4.2085, which is significantly greater than unity. This means that goods and services are not complements, suggesting that the data do not support the story of Ngai and Pissarides (2007).

While persistence of TFP shock in manufacturing is somewhat modest (0.6990), that in non-manufacturing is highly persistent (0.9448). The same is true for the investment-specific technology shock (0.6916 in manufacturing and 0.8188 in non-manufacturing). Skill-specific shock is less persistent that unskilled specific technology shock (0.6969 against 0.7868). The opposite is true for wage markup shocks. While persistence for wage markup shock for skilled is estimated to be 0.9561, that for unskilled is smaller with 0.8059.

5 Comparative Statics Exercises

Based on the parameter estimates in Section 4, we perform comparative statics exercises in order to understand factors behind the changes in the labor market in Japan. Alternatively, we could estimate our model with the data after 1995 to see what changes in the model parameters can account for the stylized facts. However, we think that it may not be an ideal way to explain changes in the labor market. First, it is possible that the Japanese labor market is still in its transition to a new steady state and using the transition period may give us somewhat misleading results. Second, it may be difficult to disentangle and identify the exact factor(s) accounting for the observed changes in the Japanese labor market because it is highly likely that the data contain many structural factors that affect the Japanese economy during this time period. For these reasons, we believe that it is better to take a comparative statics approach.

To simplify presentation below, let us define for $j = 1, 2$ in the steady state

$$Z_j \equiv \mu_j \left(\frac{\psi_u U_j}{\psi_s S_j} \right)^{\sigma_j} + (1 - \mu_j) \left\{ \lambda_j \left(\frac{K_j}{\psi_s S_j} \right)^{\rho_j} + (1 - \lambda_j) \right\}^{\frac{\sigma_j}{\rho_j}} . \tag{23}$$

Given the steady-state value of $r = \frac{1}{\beta} - (1 - \delta)$ and other parameter values, together with the definitions of Z_1 and Z_2 in (23), the following non-linear system of 12 equations characterizes the steady state of this economy.

$$\frac{Y_1}{\psi_s S_1} = A_1 (Z_1)^{\frac{1}{\sigma_1}} \tag{24}$$

$$\frac{Y_2}{\psi_s S_2} = A_2 (Z_2)^{\frac{1}{\sigma_2}} \tag{25}$$

$$\frac{C_1}{\psi_s S_1} = \frac{Y_1}{\psi_s S_1} - \delta \frac{K_1}{\psi_s S_1} - \delta \frac{K_2}{\psi_s S_2} \frac{S_2}{S_1} \tag{26}$$

$$\frac{C_2}{\psi_s S_2} = \frac{Y_2}{\psi_s S_2} \tag{27}$$

$$p \left(\frac{C_2}{\psi_s S_2} \right)^{\frac{1}{\kappa}} = \frac{(1 - \gamma)}{\gamma} \left(\frac{C_1}{\psi_s S_1} \frac{S_1}{S_2} \right)^{\frac{1}{\kappa}} \tag{28}$$

$$\left(\frac{w_s}{w_u} \right)^{\theta} = \frac{S_1}{U_1} \frac{\left(1 + \frac{S_2}{S_1} \right)}{\left(1 + \frac{U_2/S_2}{U_1/S_1} \frac{S_2}{S_1} \right)} \tag{29}$$

$$r = (1 - \mu_1) \lambda_1 A_1 \left(\frac{K_1}{\psi_s S_1} \right)^{\rho_1 - 1} (Z_1)^{\frac{1-\sigma_1}{\sigma_1}} \left\{ \lambda_1 \left(\frac{K_1}{\psi_s S_1} \right)^{\rho_1} + (1 - \lambda_1) \right\}^{\frac{\sigma_1 - \rho_1}{\rho_1}} \tag{30}$$

$$\frac{r}{p} = (1 - \mu_2) \lambda_2 A_2 \left(\frac{K_2}{\psi_s S_2} \right)^{\rho_2 - 1} (Z_2)^{\frac{1-\sigma_2}{\sigma_2}} \left\{ \lambda_2 \left(\frac{K_2}{\psi_s S_2} \right)^{\rho_2} + (1 - \lambda_2) \right\}^{\frac{\sigma_2 - \rho_2}{\rho_2}} \tag{31}$$

$$w_s = (1 - \mu_1)(1 - \lambda_1)(A_1)^{\sigma_1} \left(\frac{Y_1}{\psi_s S_1} \right)^{1 - \sigma_1} \left\{ \lambda_1 \left(\frac{K_1}{\psi_s S_1} \right)^{\rho_1} + (1 - \lambda_1) \right\}^{\frac{\sigma_1 - \rho_1}{\rho_1}} \tag{32}$$

$$\frac{w_s}{p} = (1 - \mu_2)(1 - \lambda_2)(A_2)^{\sigma_2} \left(\frac{Y_2}{\psi_s S_2} \right)^{1 - \sigma_2} \left\{ \lambda_2 \left(\frac{K_2}{\psi_s S_2} \right)^{\rho_2} + (1 - \lambda_2) \right\}^{\frac{\sigma_2 - \rho_2}{\rho_2}} \tag{33}$$

$$w_u = \mu_1 (A_1)^{\sigma_1} \left(\frac{Y_1}{\psi_s S_1} \right)^{1 - \sigma_1} \left(\psi_u \frac{U_1}{S_1} \right)^{\sigma_1 - 1} \psi_b \tag{34}$$

$$\frac{w_u}{p} = \mu_2 (A_2)^{\sigma_2} \left(\frac{Y_2}{\psi_s S_2} \right)^{1 - \sigma_2} \left(\psi_u \frac{U_2}{S_2} \right)^{\sigma_2 - 1} \psi_b \tag{35}$$

This system describes the steady-state relationship among the following 12 variables:

$$\frac{Y_1}{S_1}, \frac{Y_2}{S_2}, \frac{C_1}{S_1}, \frac{C_2}{S_2}, \frac{K_1}{S_1}, \frac{K_2}{S_2}, \frac{U_1}{S_1}, \frac{U_2}{S_2}, \frac{S_2}{S_1}, p, w_s, w_u. \tag{36}$$

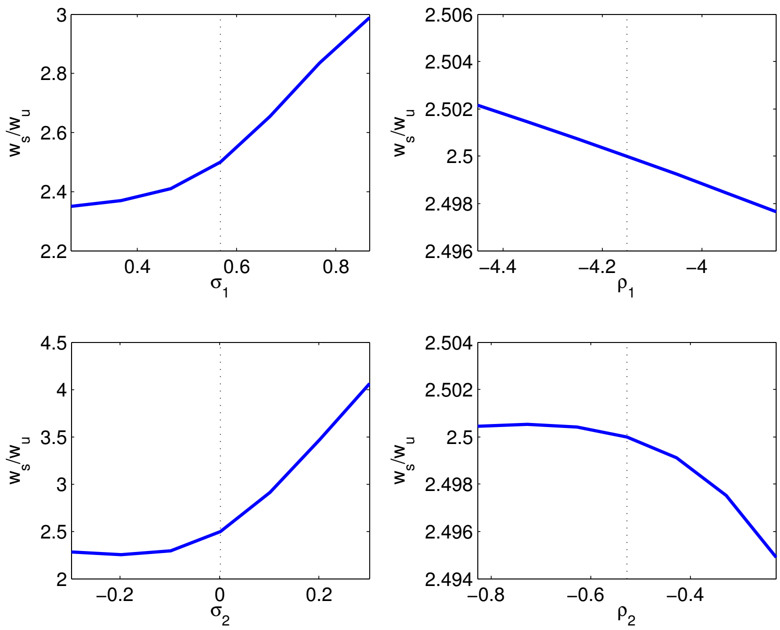


Figure 6: Changes in the Skill Premium

Note: The left panels depict changes in the skill premium (vertical axis) as σ_1 and σ_2 move. The right panels illustrates changes in the skill premium as we vary ρ_1 and ρ_2. The dashed vertical line indicates posterior mean of the corresponding parameter.

Together with the steady-state values of $\frac{U_1}{S_1}$, $\frac{U_2}{S_2}$, and $\frac{S_2}{S_1}$, the steady-state skill premium satisfies (29). We want the model to capture the realistic feature of the Japanese economy. Especially, we think that the size of skill premium is important because this characterizes two different types of workers. Thus, we impose the steady-state skill premium (w_s/w_u) to be 2.5, which roughly corresponds to the average skill premium in 1994. We will choose the value of θ, such that we can hit the target $w_s/w_u = 2.5$. Since we have imposed $\frac{U_1}{S_1}$, $\frac{U_2}{S_2}$, and $\frac{S_2}{S_1}$ in the estimation in the previous section, we can pin down the value of θ. The skill-premium-consistent value of θ is 2.3581. Using the posterior means, we will back out the share parameters μ_j for $j = 1, 2$, γ, and the productivity level of unskilled worker relative to skilled one $\frac{\psi_u}{\psi_s}$. To do this, we assume that the relative productivity level in non-manufacturing $\frac{A_2}{A_1}$ is unity and $\lambda_1 = \lambda_2 = 0.4$.

In what follows, we will look at how the steady-state values would change as we alter the values of σ_1, σ_2, ρ_1, and ρ_2, which are all relevant to the degree of capital-skill complementarity. An increase in σ means that the elasticity of substitution between capital and unskilled labor increases. Similarly, a rise in ρ results in higher substitutability between capital and skilled labor.

Figure 6 depicts changes in the skill premium as we vary σ's and ρ's. The top left panel shows changes in the skill premium as σ_1 moves and the bottom left figure corresponds to the one when we change σ_2. The top right plot illustrates changes in the skill premium

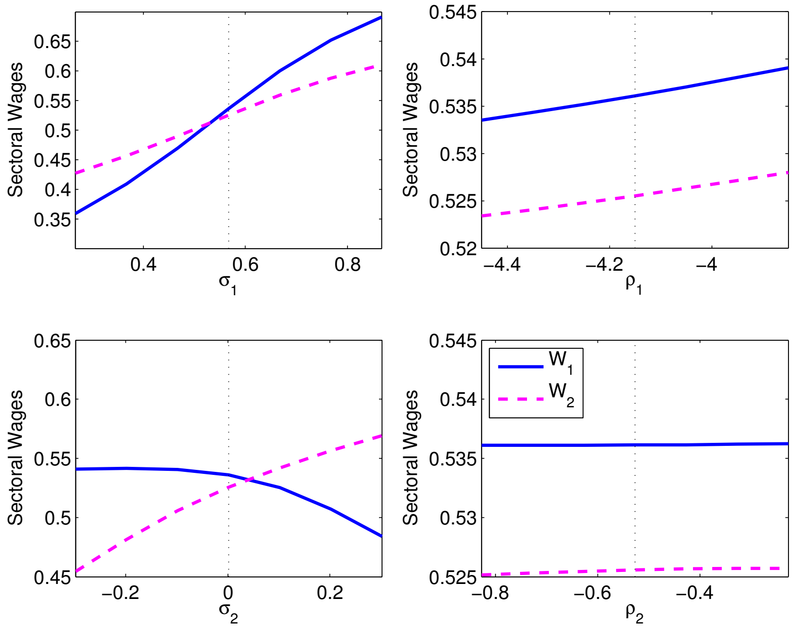


Figure 7: Changes in Sectoral Wages

Note: The left panels depict changes in sectoral wages (vertical axis) as σ_1 and σ_2 move. The right panels illustrates changes in sectoral wages as we vary ρ_1 and ρ_2. The dashed vertical line indicates posterior mean of the corresponding parameter.

with different values of ρ_1 and the bottom right figure depicts how the skill premium varies as ρ_2 changes. The vertical dashed lines indicate the posterior mean of the corresponding parameter.

Reductions in σ_1 or σ_2 and increases in ρ_1 or ρ_2 lower the skill premium. Given parameter values, changes in ρ_1 or ρ_2 do not affect the skill premium much. The skill premium becomes smaller as σ goes down and/or as ρ increases. Recall that when $\sigma_j > \rho_j$, capital-skill complementarity exists. This means that reductions in the degree of capital-skill complementarity will dampen the skill premium. This is quite intuitive. Given the high skill premium, it is reasonable to hire skilled labor since it complements the existing capital stock. With the lower capital-skill complementarity, now it is not desirable to keep hiring skilled labor any more. Cheaper unskilled labor will replace expensive skilled labor. Thus, any reduction in the capital-skill complementarity (through one of or any of σ_1, σ_2, ρ_1, and ρ_2) can lower the skill premium and is a candidate to explain the stylized facts mentioned in Section 2.

Although changes in these parameters can explain the decline in the skill premium, inspecting Figure 7 reveals that changes in σ_1, ρ_1, and ρ_2 cannot explain both changes in the skill premium and the sectoral wages presented in Section 2. Figure 7 illustrates changes in sectoral wages as we move σ's and ρ's. As σ_1 decreases, or as ρ_1 and σ_2 increase, both manufacturing and non-manufacturing wages move in the same direction. This is not consistent with the pattern observed in the data. Higher ρ's induces sectoral wages to

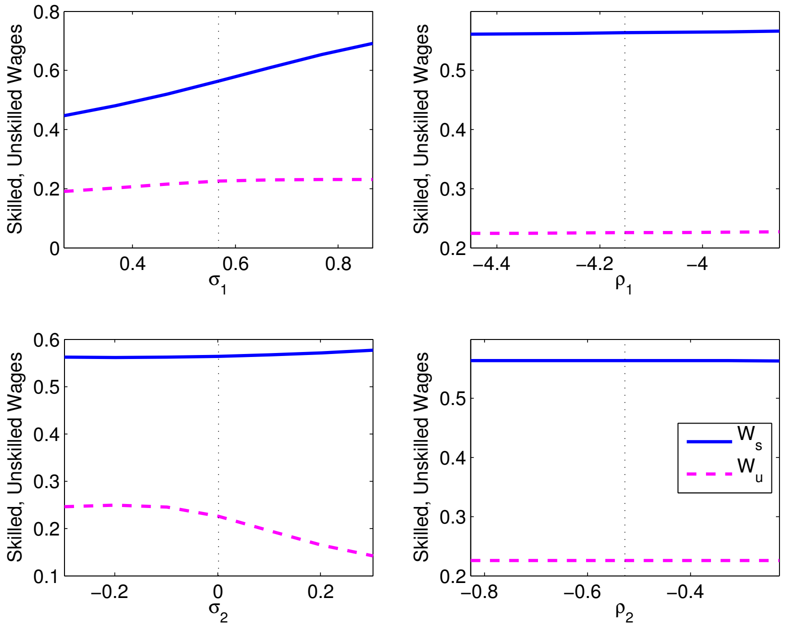


Figure 8: Changes in Skilled and Unskilled Wages

Note: The left panels depict changes in skilled and unskilled wages (vertical axis) as σ_1 and σ_2 move. The right panels illustrates changes in skilled and unskilled wages as we vary ρ_1 and ρ_2. The dashed vertical line indicates posterior mean of the corresponding parameter.

increase. Reductions in σ_1 would lower both manufacturing and services wages. Since the speed of reduction is slightly slower for non-manufacturing wage, non-manufacturing wage could become higher than manufacturing wage when a drop in σ_1 is sufficiently large.

It is a decrease in σ_2 that explains both the lower skill premium and the lower non-manufacturing wage. As σ_2 decreases from the posterior mean, which is indicated as the vertical line in the figure, we can see that while manufacturing wage increases slightly, non-manufacturing wage reduces considerably. This is consistent with what we have observed in the Japanese labor market since the mid 1990s.

Figure 8 compares changes in skilled and unskilled wages as we alter σ's and ρ's. These pictures indicate that skilled and unskilled wages move in the same direction as the capital-skill complementarity in manufacturing reduces. On the other hand, skilled wage drops and unskilled wage increases as capital-skill complementarity in non-manufacturing decreases.

Figure 9 reveals why a reduction in σ_2 leads to the decline in non-manufacturing wage, while manufacturing wage slightly increases. The reduction of capital-skill complementarity through σ_2 is associated with a large increase in share of unskilled labor in non-manufacturing sector. To elaborate on the importance of this factor, let us express changes in the sectoral wage (15) as

$$dw_j = (1-\tau_j)dw_s + \tau_j dw_u + (w_u - w_s)d\tau_j$$

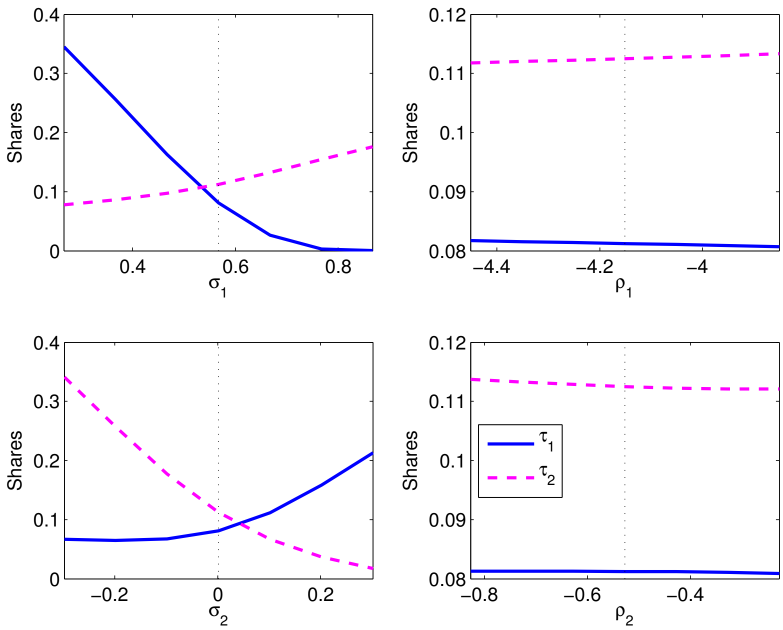


Figure 9: Changes in Unskilled Shares

Note: The left panels depict changes in the unskilled share (vertical axis) as we vary σ_1 and σ_2. The right panels illustrates changes in the unskilled share as ρ_1 and ρ_2 move. The dashed vertical line indicates posterior mean of the corresponding parameter.

$$= dw_s - \tau_j(dw_s - dw_u) + (w_u - w_s)d\tau_j \tag{37}$$

for $j = 1, 2$. The second term in (37) represents changes in the skill premium, which are negative in the data. Thus, the contribution of changes in the skill premium becomes positive. Given the positive skill premium, the last term (changes in the unskilled labor share, $d\tau_j$) has negative impact on the sectoral wages. While the reduced capital-skill complementarity in non-manufacturing hardly changes the unskilled share in manufacturing, it drastically expands the unskilled share in non-manufacturing. The contribution of the increased unskilled share in non-manufacturing dominates the positive effect that stems from the lower skill premium. As a result, non-manufacturing wage declines. In contrast, manufacturing wage does not change much due to very small share of unskilled labor in manufacturing.

In terms of unskilled share, the opposite happens when σ_1 decreases. The unskilled share in manufacturing rises and that in non-manufacturing slightly declines. The rise in the unskilled share and the reduction in the skilled wage together dampen manufacturing wage. The drop in the skilled wage dominates other factors in non-manufacturing. As a result, declines in non-manufacturing wage are slower than those in manufacturing wage. Increases in ρ's hardly affect the unskilled share in both manufacturing and non-manufacturing. Given the relatively small reduction in the skilled wage, the positive effect from changes in the skill premium dictates sectoral wages. As a result, we see both sectoral wages to go up as ρ

increases.

We can explore other possibilities. However, changes in other parameter values do not affect the steady-state values, especially the skill premium and the sectoral wages, in a way that is consistent with the data. Changes in other parameter values can result in the reduction in the skill premium. For example, a drop in γ lowers the skill premium. Also, an increase in θ reduces the skill premium. However, it turns out that these changes move the sectoral wages in the same direction and cannot account for the observed changes in the sectoral wages in the data. Although an increase in b also lowers the skill premium, this induces a reduction in manufacturing wage and a rise in non-manufacturing wage. These are the opposite of what we have seen in the data.

To sum up, the lower capital-skill complementarity in non-manufacturing, especially the reduction in σ_2 is the only possible scenario that is consistent with the stylized facts outlined in Section 2, among different possibilities. That is, while manufacturing wage increases slightly, non-manufacturing wage drops, and the skill premium declines. The value of σ_2 that is consistent with the lower skill premium in the recent time periods, 2.3, is $\sigma_2 = -0.098$.

6 Conclusion

While many studies document and offer explanations for the rises in the skill premium across economies, less attention has been paid on the declined skill premium observed in some countries over the past few decades. This paper documents changes in the Japanese labor market both at aggregate and industry levels. We observe declines in the skill premium, together with the rise in the sectoral wage gap, and the increase in the unskilled share in non-manufacturing.

In order to provide a consistent explanation for the above-mentioned changes, we build a two-sector neo-classical general equilibrium model with two types of labor (skilled and unskilled), in which production technology features capital-skill complementarity. Two sectors can differ in terms of the degree of capital-skill complementarity. We take our model to the Japanese data with Bayesian methods. We find that there exists sectoral heterogeneity in capital-skill complementarity. Based on the estimated structural parameters, we show that the decline in capital-skill complementarity through the decline in the elasticity of substitution between capital and unskilled in non-manufacturing sector can account for the observed changes in the Japanese data.

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Appendix

A Log-Linearized System

$$
\begin{aligned}
\hat{c}_t &= \omega_1 \hat{c}_{1,t} + (1-\omega_1)\hat{c}_{2,t} \\
\hat{\Lambda}_t &= -\frac{1}{\kappa}\hat{c}_{1,t} + \left(\frac{1}{\kappa} - 1\right)\hat{c}_t \\
\hat{\Lambda}_t + \hat{p}_t &= -\frac{1}{\kappa}\hat{c}_{2,t} + \left(\frac{1}{\kappa} - 1\right)\hat{c}_t \\
\hat{h}_t &= \omega_s \hat{s}_t + (1-\omega_s)\hat{u}_t \\
\hat{\Lambda}_t + \hat{w}_{s,t} &= \frac{1}{\theta}\hat{s}_t + \left(\frac{1}{\eta} - \frac{1}{\theta}\right)\hat{h}_t + \hat{m}_{s,t} \\
\hat{\Lambda}_t + \hat{w}_{u,t} &= \frac{1}{\theta}\hat{u}_t + \left(\frac{1}{\eta} - \frac{1}{\theta}\right)\hat{h}_t + \hat{m}_{u,t} \\
\hat{\Lambda}_t &= \hat{\Psi}_{1,t} + \hat{\xi}_{1,t} + \varphi\left\{\hat{i}_{1,t-1} - (1+\beta)\hat{i}_{1,t} + \beta\mathbb{E}_t[\hat{i}_{1,t+1}]\right\} \\
\hat{\Lambda}_t &= \hat{\Psi}_{2,t} + \hat{\xi}_{2,t} + \varphi\left\{\hat{i}_{2,t-1} - (1+\beta)\hat{i}_{2,t} + \beta\mathbb{E}_t[\hat{i}_{2,t+1}]\right\} \\
\hat{\Psi}_{1,t} &= \beta\mathbb{E}_t\left[r\hat{\Lambda}_{t+1} + r\hat{r}_{1,t+1} + (1-\delta)\hat{\Psi}_{1,t+1}\right] \\
\hat{\Psi}_{2,t} &= \beta\mathbb{E}_t\left[r\hat{\Lambda}_{t+1} + r\hat{r}_{2,t+1} + (1-\delta)\hat{\Psi}_{2,t+1}\right] \\
\hat{x}_{1,t} &= (\sigma_1 - \rho_1)\left\{\omega_{k_1}\hat{k}_{1,t} + (1-\omega_{k_1})(\hat{\psi}_{s,t} + \hat{s}_{1,t})\right\} \\
\hat{x}_{2,t} &= (\sigma_2 - \rho_2)\left\{\omega_{k_2}\hat{k}_{2,t} + (1-\omega_{k_2})(\hat{\psi}_{s,t} + \hat{s}_{2,t})\right\} \\
\hat{r}_{1,t} &= (1-\sigma_1)\hat{y}_{1,t} + \sigma_1\hat{a}_{1,t} + (\rho_1 - 1)\hat{k}_{1,t} + \hat{x}_{1,t} \\
\hat{r}_{2,t} - \hat{p}_t &= (1-\sigma_2)\hat{y}_{2,t} + \sigma_2\hat{a}_{2,t} + (\rho_2 - 1)\hat{k}_{2,t} + \hat{x}_{2,t} \\
\hat{w}_{s,t} &= (1-\sigma_1)\hat{y}_{1,t} + \sigma_1\hat{a}_{1,t} + \rho_1\hat{\psi}_{s,t} + (\rho_1 - 1)\hat{s}_{1,t} + \hat{x}_{1,t} \\
\hat{w}_{s,t} - \hat{p}_t &= (1-\sigma_2)\hat{y}_{2,t} + \sigma_2\hat{a}_{2,t} + \rho_2\hat{\psi}_{s,t} + (\rho_2 - 1)\hat{s}_{2,t} + \hat{x}_{2,t} \\
\hat{w}_{u,t} &= (1-\sigma_1)\hat{y}_{1,t} + \sigma_1\hat{a}_{1,t} + \sigma_1\hat{\psi}_{u,t} + (\sigma_1 - 1)\hat{u}_{1,t} \\
\hat{w}_{u,t} - \hat{p}_t &= (1-\sigma_2)\hat{y}_{2,t} + \sigma_2\hat{a}_{2,t} + \sigma_2\hat{\psi}_{u,t} + (\sigma_2 - 1)\hat{u}_{2,t} \\
\hat{y}_{1,t} &= \hat{a}_{1,t} + \omega_{u_1}(\hat{u}_{1,t} + \hat{\psi}_{u,t}) + (1-\omega_{u_1})\hat{x}_{1,t} \\
\hat{y}_{2,t} &= \hat{a}_{2,t} + \omega_{u_2}(\hat{u}_{2,t} + \hat{\psi}_{u,t}) + (1-\omega_{u_2})\hat{x}_{2,t} \\
\hat{k}_{1,t+1} &= \delta\hat{i}_{1,t} + (1-\delta)\hat{k}_{1,t} \\
\hat{k}_{2,t+1} &= \delta\hat{i}_{2,t} + (1-\delta)\hat{k}_{2,t} \\
\hat{s}_t &= f_s\hat{s}_{1,t} + (1-f_s)\hat{s}_{2,t} \\
\hat{u}_t &= f_u\hat{u}_{1,t} + (1-f_u)\hat{u}_{2,t} \\
\hat{y}_{1,t} &= \omega_c\hat{c}_{1,t} + \omega_i\hat{i}_{1,t} + (1-\omega_c-\omega_i)\hat{i}_{2,t} \\
\hat{y}_{2,t} &= \hat{c}_{2,t}
\end{aligned}
$$

$$
\begin{aligned}
\hat{a}_{1,t} &= \rho_{a_l}\hat{a}_{1,t-1} + \varepsilon_{a_1,t} \\
\hat{a}_{2,t} &= \rho_{a_2}\hat{a}_{2,t-1} + \varepsilon_{a_2,t} \\
\hat{\psi}_{s,t} &= \rho_{\psi_s}\hat{\psi}_{s,t-1} + \varepsilon_{\psi_s,t} \\
\hat{\psi}_{u,t} &= \rho_{\psi_u}\hat{\psi}_{u,t-1} + \varepsilon_{\psi_u,t} \\
\hat{\xi}_{l,t} &= \rho_{\xi_l}\hat{\xi}_{l,t-1} + \varepsilon_{\xi_l,t} \\
\hat{\xi}_{2,t} &= \rho_{\xi_2}\hat{\xi}_{2,t-1} + \varepsilon_{\xi_2,t} \\
\hat{m}_{s,t} &= \rho_{m_s}\hat{m}_{s,t-1} + \varepsilon_{m_s,t} \\
\hat{m}_{u,t} &= \rho_{m_u}\hat{m}_{u,t-1} + \varepsilon_{m_u,t} \\
\hat{w}_{1,t} &= \eta_{\chi 1}\hat{\chi}_{1,t} + \eta_{w_{s_1}}\hat{w}_{s,t} + \eta_{w_{u,1}}\hat{w}_{u,t} \\
\hat{w}_{2,t} &= \eta_{\chi 2}\hat{\chi}_{2,t} + \eta_{w_{s_2}}\hat{w}_{s,t} + \eta_{w_{u,2}}\hat{w}_{u,t} \\
\hat{\chi}_{1,t} &= \eta_{u_1}\hat{u}_{1,t} + \eta_{s_1}\hat{s}_{1,t} \\
\hat{\chi}_{2,t} &= \eta_{u_2}\hat{u}_{2,t} + \eta_{s_2}\hat{s}_{2,t}
\end{aligned}
$$

where

$$
\omega_1 = \frac{\gamma(C_1)^{\frac{\kappa-1}{\kappa}}}{\gamma(C_1)^{\frac{\kappa-1}{\kappa}} + (1-\gamma)(C_2)^{\frac{\kappa-1}{\kappa}}} = \frac{C_1}{C_1 + pC_2} \qquad \omega_s = \frac{(S)^{\frac{\theta+1}{\theta}}}{(S)^{\frac{\theta+1}{\theta}} + (U)^{\frac{\theta+1}{\theta}}} \qquad \varphi = \Phi''(1)
$$

$$
\omega_{k_1} = \frac{\lambda_1(K_1)^{\rho_1}}{\lambda_1(K_1)^{\rho_1} + (1-\lambda_1)(\psi_s S_1)^{\rho_1}} \qquad \omega_{k_2} = \frac{\lambda_2(K_2)^{\rho_2}}{\lambda_2(K_2)^{\rho_2} + (1-\lambda_2)(\psi_s S_2)^{\rho_2}}
$$

$$
\omega_{u_1} = \frac{\mu_1(\psi_u U_1)^{\sigma_1}}{\mu_1(\psi_u U_1)^{\sigma_1} + (1-\mu_1)(X_1)^{\frac{\sigma_1}{(\sigma_1-\rho_1)}}} \qquad \omega_{u_2} = \frac{\mu_2(\psi_u U_2)^{\sigma_2}}{\mu_2(\psi_u U_2)^{\sigma_2} + (1-\mu_2)(X_2)^{\frac{\sigma_2}{(\sigma_2-\rho_2)}}}
$$

$$
f_s = \frac{S_1}{S} \qquad f_u = \frac{U_1}{U}
$$

$$
\omega_c = \frac{C_1}{Y_1} \qquad \omega_i = \frac{I_1}{Y_1}
$$

$$
\eta_{\chi 1} = \frac{1-\pi}{\frac{S_1}{U_1}\pi + 1} \qquad \eta_{\chi 2} = \frac{1-\pi}{\frac{S_2}{U_2}\pi + 1}
$$

$$
\eta_{w_{s_1}} = \left(1 + \frac{1}{\frac{S_1}{U_1}\pi}\right)^{-1} \qquad \eta_{w_{s_2}} = \left(1 + \frac{1}{\frac{S_2}{U_2}\pi}\right)^{-1}
$$

$$
\eta_{w_{u_1}} = \left(1 + \frac{S_1}{U_1}\pi\right)^{-1} \qquad \eta_{w_{u_2}} = \left(1 + \frac{S_2}{U_2}\pi\right)^{-1}
$$

B Data Construction

Since there are no quarterly output and price data at the sectoral level, we assume that durable goods and investment goods for residential and business fixed investment are produced by the manufacturing industry (Y_1). Also, we assume that non-durable goods and services are produced by non-manufacturing industry (Y_2). We construct price indices for each output accordingly (P_1 and P_2). The relative price (p) is defined as P_2/P_1. We obtain GDP components and corresponding price indices from the National Accounts by the Cabinet Office.

Population (15 years old and over) consists of labor force and non-labor force (excluding people with unknown labor status), which are from the Labour Force Survey (LFS) by the Statistics Bureau of the Ministry of Internal Affairs and Communications. This is used to convert quantity variables in per capita term.

We construct sectoral hourly wage (W_1 and W_2) by dividing nominal wage bill per worker by total hours worked per worker for each industry. Before 1990, we use data from establishments with 30 and more employees. After 1990, we use data from establishments with 5 or more employees. The data are taken from the Monthly Labour Survey (MLS) by the Ministry of Health, Labour and Wealth.

Part-time workers are defined as those who work less than the regular (full-time) workers per day or per week. After 1990, we use the number of full-time (L_s) and part-time (L_u) workers reported in the MLS. However, there is no official statistics before 1990. We extrapolate the number reported in the MLS by using the data from the LFS. We use the number of employees whose weekly hours worked are 35 hours or more for the full-time workers and that with less than 35 hours is used for part-time workers.

We construct the average hours worked per skilled worker by using the following relationship:

$$h = \frac{h_s L_s + h_u L_u}{L_s + L_u} = h_s \left(\frac{L_s}{L_s + L_u} + \zeta \frac{L_u}{L_s + L_u} \right),$$

where h is the average hours worked (regardless of skilled or unskilled) per worker, h_s and h_u are the average hours worked per skilled and unskilled workers, L_s and L_u denote the number of skilled and unskilled workers, and $\zeta = \frac{h_u}{h_s}$. To measure h, we use the MLS. After 1990, we use data from establishments with five and more employees. Prior to 1990, we use data from establishments with 30 and more employees. ζ is taken from the MLS after 1990 (establishments with five or more employees). Before 1990, we use the Basic Survey on Wage Structure by utilizing linear interpolation. Given h, L_s, L_u, and ζ, we construct h_s and then we calculate $h_u = \zeta h_s$. Finally, we construct by $S = h_s L_s$ and $U = h_u L_u$.