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“The Impact of Taxes and Transfers on Skill Premium”

Shuhei Takahashi  Ken Yamada

August 2017

KYOTO UNIVERSITY
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The Impact of Taxes and Transfers on Skill Premium

Shuhei Takahashi† Ken Yamada‡

August 2017

Abstract

The level of wage inequality has varied across advanced industrial countries. One of the main reasons has been a significant difference in the skill wage premium. This study analyzes the impact of taxes and transfers on the skill wage premium and social welfare in the context of a heterogeneous-agents incomplete-markets model, in which the population consists of skilled workers and unskilled workers, and the production technology exhibits capital-skill complementarity. The analysis indicates that a significant fraction of the difference in the skill wage premium between the United States and Japan can be accounted for by differences in the tax system.

KEYWORDS: Skill premium; capital-skill complementarity; incomplete markets; capital income taxation; composition effect.


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Introduction

The level of wage inequality has varied widely across advanced industrial countries (Krueger, Perri, Pistaferri, and Violante, 2010). One of the main reasons for this has been a significant difference in the skill wage premium, defined as the ratio of the average wage of college graduate workers to that of non-college graduate workers. When the United States and Japan, two of the largest economies in the world, are compared, the variance of the log hourly wage was 47 percent higher in the United States than in Japan in the year 2000, while the college wage premium was 26 percent higher in the United States than in Japan (Heathcote, Perri, and Violante, 2010; Lise, Sudo, Suzuki, Yamada, and Yamada, 2014).

Despite the large difference in the skill wage premium between the United States and Japan, it would be fair to say that the difference in the level of technology or the share of the skilled population was insignificant around the year 2000. In fact, the shares of population with tertiary education were 36.5 percent in the United States and 33.6 percent in Japan in the year 2000 (OECD, 2015). The difference in the skill wage premium between the two countries cannot simply be explained by differences in those supply and demand factors. In this study, we focus on the impact of institutional differences between the two countries.

In particular, we examine the extent to which the difference in the skill wage premium between the United States and Japan can be accounted for by differences in the tax system. Interestingly, there was a notable difference in the tax rate on capital income between the two countries around the year 2000, while there was no difference in the tax rates on consumption or labor income, as detailed in the next section. In this study, we develop a general equilibrium model, in which taxes and transfers affect the labor market equilibrium through a shift in the supply of and demand for physical capital, as well as a shift in the relative supply of and demand for skilled labor.

We consider a heterogeneous-agents incomplete-markets model, in which the population consists of skilled workers and unskilled workers, and the production technology exhibits capital-skill complementarity. Capital-skill complementarity is a fundamental source of educational wage differentials in a modern economy. We calibrate the model to the U.S. economy and quantitatively assess the impact of a change in policy that replaces the U.S. tax system with the
Japanese tax system on the skill wage premium and social welfare. We find that the skill wage premium declines from 1.75 to 1.63 in the heterogeneous-agents incomplete-markets model as a consequence of a change in policy that raises the tax rate on capital income and spends the incremental revenue on transfers to households. The magnitude of this reduction corresponds to 42 percent of the actual difference in the skill wage premium between the two countries. We show that 72 percent of the reduction in the skill wage premium is attributable to the equilibrium effect with respect to a change in the relative marginal product, while the remaining 28 percent is attributable to the mechanical effect with respect to a change in the relative average productivity. We further show that such a change in tax policy, which reduces persistent wage differentials between skilled workers and unskilled workers, can effectively improve social welfare.

This paper is closely related to the quantitative macroeconomic literature on the role of taxes and transfers in the heterogeneous-agents incomplete-markets model of Huggett (1993) and Aiyagari (1994), extended to allow for endogenous labor supply. Among others, Flodén and Lindé (2001) and Alonso-Ortiz and Rogerson (2010) focus on labor income taxes and transfers, Nakajima and Takahashi (2016) focus on consumption taxes and transfers, and Aiyagari and McGrattan (1998) and Flodén (2001) focus on government debt and transfers. We extend their models by incorporating two types of labor that differ in the degree of substitution for capital and focus mainly on capital income taxes and transfers. Slavík and Yazici (2016) use a model similar to ours to examine the causes of changes in the skill wage premium over time in the United States. In contrast, our analysis contributes to understanding the role of taxes and transfers in accounting for cross-country differences in the skill wage premium. In this regard, this study is an extension of the work by Prescott (2004) and Alonso-Ortiz and Rogerson (2010), who examine the role of taxes and transfers in accounting for cross-country differences in labor supply and productivity, respectively. In addition, our analysis contributes to understanding differences in quantitative predictions regarding the impact of taxes and transfers between the heterogeneous-agents incomplete-markets model and the representative-agent model.

The rest of the paper proceeds as follows. Section 2 compares the skill wage premium and the tax system between the United States and Japan. Section 3 presents the model and describes
the equilibrium allocation. Section 4 discusses the measurement and decomposition of the impact of taxes and transfers on the skill wage premium. Section 5 describes the calibration procedure and provides quantitative results on the skill wage premium and social welfare. The final section summarizes and concludes.

2 US-Japan Comparison

We compare the skill wage premium and the tax system between the United States and Japan.

Figure 1: The skill wage premium in the United States and Japan

2.1 Differences in skill premium

The skill wage premium has been significantly higher in the United States than in Japan. Figure 1 illustrates the skill wage premium between the years 1995 and 2005 in the United States and between the years 1996 and 2006 in Japan. The data used in the analysis are from the Current Population Survey (CPS) for the United States and the Employment Status Survey (ESS) for Japan. The ESS is the most comparable household survey to the CPS for the purpose of the analysis here, and has been conducted every five years in Japan by the Ministry of Internal Affairs and Communications. We select the sample and construct variables in the same way as Heathcote, Perri, and Violante (2010) for both countries and calculate the skill wage premium for men and women aged 25 to 60. In the calculation, four-year college graduates are classified as skilled, and the rest are classified as unskilled. During the period, the skill wage premium
was on average 1.75 in the United States and 1.44 in Japan.

The difference in the skill wage premium cannot be explained simply by differences in the composition of the workforce between the two countries. First of all, the supply of skilled labor was similar between the two countries relative to other OECD countries, and, if anything, greater in the United States than in Japan. During the period, the share of the skilled population was on average 29 percent in the United States and 22 percent in Japan. Moreover, even when we reweight the Japanese sample such that it has the same distribution of age, sex, and education as the U.S. sample using the DiNardo, Fortin, and Lemieux (1996) method, the skill wage premium remains almost unchanged (Figure 1).

The difference in the skill wage premium has persisted for a long time between the two countries. Educational wage differentials were consistently greater in the United States than in Japan from the late 1960s to the 1980s (Katz, Loveman, and Blanchflower, 1995). The skill wage premium has increased substantially in the United States in recent years, but the magnitude of the increase over time has been small relative to the magnitude of the difference in the skill wage premium between the two countries (Figure 1).

2.2 Differences in the tax system

The capital income tax rate has been significantly higher in Japan than in the United States. Trabandt and Uhlig (2011) calculate average marginal tax rates in the United States and many European countries for the years 1995 to 2007. Gunji and Miyazaki (2011) provide comparable average marginal tax rates in Japan during the corresponding period. Interestingly, during the period, the capital income tax rate was on average 52 percent in Japan as opposed to 36 percent in the United States, while the consumption and labor income tax rates were on average 5 percent and 28 percent, respectively, in both countries. Among the countries analyzed in Trabandt and Uhlig (2011), the capital income tax rate was near the average in the United States and highest in Japan. Importantly, there was not much difference in the progressivity of

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1 Alternatively, even when we adjust for differences in the age, sex, and education composition of the workforce across countries in a way similar to Krusell, Ohanian, Rios-Rull, and Violante (2000), who adjust for changes in the workforce composition over time, the difference in the skill wage premium mostly still remains.

2 We adjust the results of Gunji and Miyazaki (2011) on the labor and capital income tax rates in Japan in a way similar to Nutahara (2015).
labor income taxes between the two countries during the period (See the OECD tax database for details). A key feature of the Japanese tax system is the higher rate of capital income taxes due in large part to the higher rate of corporate tax. Therefore, in the subsequent analysis, we focus mainly on the impact of a change in policy that raises the tax rate on capital income on the skill wage premium.

3 The Model

We consider the heterogeneous-agents incomplete-markets model, which is an extension of the model in Alonso-Ortiz and Rogerson (2010), who incorporate labor income taxes and transfers into the heterogeneous-agents incomplete-markets model of Chang and Kim (2007). Our model differs from theirs in that the population consists of skilled workers and unskilled workers, and the production technology exhibits capital-skill complementarity. The difference between skilled workers and unskilled workers lies in the degree of substitution for capital. We consider an extended version of the model, in which the productivity process differs between skilled workers and unskilled workers in Appendix A.1. We present a representative-agent version of the model in Appendix A.2.

3.1 Households

The economy is populated by a continuum of infinitely-lived agents of unit mass who are either skilled or unskilled indexed by \( j \in \{S, U\} \). Preferences are described by:

\[
E_t \sum_{t=\tau}^{\infty} \beta^{t-\tau} U_j(c_t, h_t),
\]

where \( \beta \) is the discount factor, \( c_t \) consumption, and \( h_t \) hours worked in period \( t \). Following Alonso-Ortiz and Rogerson (2010), we specify the instantaneous utility function to be:

\[
U_j(c_t, h_t) = \ln c - \psi_j h_t \quad \text{for } j \in \{S, U\}.
\]
We assume indivisible labor, i.e. \( h_t \in \{0, \tilde{h}_j\} \), and focus on the employment decision, which is shown to be important in accounting for cross-country differences in productivity (Alonso-Ortiz and Rogerson, 2010).

Each household earns \( x_t w_{jt} h_t \), according to idiosyncratic shocks to productivity \( x_t \), the market wage rate \( w_{jt} \), and hours worked \( h_t \), and receives lump-sum transfers from the government to each household \( f_t \). Productivity evolves stochastically according to the transition probability function \( \pi(x'|x) = \Pr(x_{t+1} \leq x_t | x_t = x) \). We specify the idiosyncratic productivity process to be the first-order autoregressive process:

\[
\ln x_t = \varrho \ln x_{t-1} + \epsilon_t, \tag{3}
\]

where \( \epsilon \) is normally distributed with mean \( \nu \) and standard deviation \( \zeta \). We adjust \( \nu \) to normalize the average idiosyncratic productivity to unity, i.e., \( \mathbb{E}(x_t) = 1 \), as in the analysis of Aiyagari and McGrattan (1998). Each household can save but face a borrowing constraint: \( a_{t+1} \geq 0 \), where assets \( a_t \) consist of physical capital and government debt. The budget constraint can be written as:

\[
(1 + \tau_c) c_t = (1 - \tau_n) x_t w_{jt} h_t + [1 + (1 - \tau_k) r_t] a_t - a_{t+1} + f_t, \tag{4}
\]

\[
c_t \geq 0, \quad a_{t+1} \geq 0, \quad h_t \in \{0, \tilde{h}_j\},
\]

where \( r_t \) is the rental price of capital. A key feature of the heterogeneous-agents incomplete-markets model is that households adjust their savings and labor supply to self-insure against idiosyncratic shocks to their productivity under the borrowing constraint.

We now consider a recursive equilibrium. We denote by \( V^E \) the present value of household utility when being employed, \( V^N \) the present value of household utility when not being employed, and \( \xi(\tilde{a}, x, j) \) is the distribution of households. Throughout the paper, the squiggles denote normalization by \( Y \) for detrending. The value of employment can be expressed as:

\[
V^E(\tilde{a}, x, j) = \max_{\tilde{c}, \tilde{a}'} \left\{ \ln \tilde{c} - \psi_j \tilde{h}_j + \beta \mathbb{E}[V(\tilde{a}', x', j)|x] \right\} \tag{5}
\]
subject to:

$$(1 + \tau_c)\tilde{c} + (1 + g)\tilde{a}' = (1 - \tau_n)xw_jh_j + [1 + (1 - \tau_k)r]\tilde{a} + \tilde{f}, \quad \tilde{c} \geq 0, \quad \tilde{a}' \geq 0,$$

and $\xi' = \mathcal{T}(\xi)$, where $\mathcal{T}$ denote a transition operator for $\xi$. The value of non-employment can be expressed as:

$$V^N(\tilde{a}, x, j) = \max_{c,a'} \{\ln \tilde{c} + \beta \mathbb{E} [V(\tilde{a}', x', j)|x]\}$$

subject to:

$$(1 + \tau_c)\tilde{c} + (1 + g)\tilde{a}' = [1 + (1 - \tau_k)r]\tilde{a} + \tilde{f}, \quad \tilde{c} \geq 0, \quad \tilde{a}' \geq 0,$$

and $\xi' = \mathcal{T}(\xi)$. The labor supply decision can then be described by:

$$V(\tilde{a}, x, j) = \max \{V^E(\tilde{a}, x, j), V^N(\tilde{a}, x, j)\}.$$ (7)

A set of decision rules for consumption, hours worked, and asset holdings can be derived as the solution to this problem. We denote by $\tilde{c}(\tilde{a}, x, j), h(\tilde{a}, x, j),$ and $\tilde{a}'(\tilde{a}, x, j)$ the decision rules for consumption, hours worked, and asset holdings, respectively.

### 3.2 Firms

Production in the economy is summarized by an aggregate function $Y_t = F(N_{St}, N_{Ut}, K_{Et}, K_{St}; z_t)$, where $N_{St}$ is skilled labor input, $N_{Ut}$ unskilled labor input, $K_{Et}$ equipment capital input, $K_{St}$ structures capital input, and $z_t$ a measure of labor-augmenting technology in period $t$. We assume that final goods are produced by perfectly competitive firms.

We assume a constant returns-to-scale technology and specify the production function to be:

$$\mathcal{F}(N_{St}, N_{Ut}, K_{Et}, K_{St}; z_t) = K_{St}^\alpha \left[\mu(z_t N_{Ut})^\sigma + (1 - \mu) \left[\lambda K_{Et}^\rho + (1 - \lambda)(z_t N_{St})^\rho\right]\right]^{1\over \sigma}.$$ (8)

Labor-augmenting technology exhibits a deterministic trend: $z_{t+1} = (1 + g)z_t$, where $g > 0$ is the growth rate of technology. The share parameters are $0 \leq \mu, \lambda \leq 1$, and the substitution parameters are $\rho, \sigma < 1$. The elasticity of substitution between skilled labor and capital is given
by \(1/(1 - \rho)\), while the elasticity of substitution between unskilled labor and the skilled labor-capital composite is \(1/(1 - \sigma)\). The degree of diminishing marginal product differs between skilled labor and unskilled labor whenever \(\sigma \neq \rho\). Production technology exhibits capital-skill complementarity if \(\sigma > \rho\) (Krusell, Ohanian, Rios-Rull, and Violante, 2000).

Profit maximization is achieved by equating factor prices with the values of the marginal products of inputs:

\[
\tilde{w}_{St} = (1 - \alpha)(1 - \mu)(1 - \lambda)\tilde{K}_{St}^{\alpha\sigma} \left(\lambda \tilde{K}_{Et}^\sigma + (1 - \lambda)(\tilde{z}_t N_{St})^\rho\right)^{\frac{\alpha - \rho}{\rho}} \tilde{z}_t^\rho N_{St}^{\rho - 1},
\]

\[
\tilde{w}_{Ut} = \tilde{K}_{St}^{\alpha\sigma} (1 - \alpha)\mu \tilde{z}_t^\sigma N_{Ut}^{\alpha - 1},
\]

\[
r_{Et} = (1 - \alpha)(1 - \mu)\tilde{K}_{St}^{\alpha\sigma} \left[\lambda \tilde{K}_{Et}^\sigma + (1 - \lambda)(\tilde{z}_t N_{St})^\rho\right]^{\frac{\alpha - \rho}{\rho}} \lambda \tilde{K}_{Et}^{\rho - 1} - \delta_E,
\]

\[
r_{St} = \alpha \tilde{K}_{St} - \delta_U,
\]

where \(\delta_E\) and \(\delta_S\) are the depreciation rates of equipment and structures, respectively. Capital equipment and structures are equivalent for households; thus, \(r_E = r_S = r\) at the equilibrium. None of the tax rates appears in the profit-maximizing conditions (9)–(12). Basically, taxation does not play a significant role for the determination of factor prices in a partial equilibrium model. In a general equilibrium model, however, capital income taxation reduces the stock of capital and alters the relative marginal product of skilled labor, thereby influencing the skill wage premium.

### 3.3 Government

We assume that the government levies proportional taxes and spends part of the tax revenue on lump-sum transfers to households, as in many previous studies (e.g., Flodén and Lindé, 2001; Prescott, 2004; Alonso-Ortiz and Rogerson, 2010). When the government levies proportional taxes on consumption, labor income, and capital income at rates \(\tau_c\), \(\tau_n\), and \(\tau_k\), respectively, and spends the tax revenue on government consumption \(G_t\), lump-sum transfers \(F_t\), and interest payments on government debt \(B_t\), the government budget constraint can be written as:

\[
G_t + F_t + r_t B_t = B_{t+1} - B_t + \tau_c C_t + \tau_n (w_{St} N_{St} + w_{Ut} N_{Ut}) + \tau_k r_t (K_{Et} + K_{St} + B_t),
\]
where $C_t$ is aggregate household consumption. The government budget constraint can be rewritten as:

$$\bar{G} + \bar{F} + r \bar{B} = \bar{B}' - (1 + g) \bar{B} + \tau_c \bar{C} + \tau_n (\bar{w}_S N_S + \bar{w}_U N_U) + \tau_r r \left( \bar{K}_E + \bar{K}_S + \bar{B} \right).$$ (13)

We assume that $\bar{G}$ and $\bar{B}$ are exogenously given.

### 3.4 Equilibrium

The equilibrium of the economy is characterized as follows. Given policies $\bar{G}, \bar{B}, \tau_c, \tau_n, \tau_h, \bar{F}$ and initial conditions $\{z_0, \xi_0\}$, a stationary competitive equilibrium is a set of value functions $\{V^E(\bar{a}, x, j), V^N(\bar{a}, x, j), V(\bar{a}, x, j)\}$, a set of decision rules for consumption, hours worked, and asset holdings $\{\bar{c}(\bar{a}, x, j), h(\bar{a}, x, j), \bar{a}'(\bar{a}, x, j)\}$, aggregate inputs $\{N_S, N_U, \bar{K}_E, \bar{K}_S\}$, price system $\{\bar{w}_S, \bar{w}_U, r\}$, and a law of motion for the distribution $\xi' = \mathcal{T}(\xi)$ such that: the decision rules and the value functions solve the household’s problem; aggregate inputs solve the firm’s problem; the government budget is balanced; the capital market clears, i.e., $\bar{K}_E' + \bar{K}_S' + \bar{B}' = \int \bar{a}'(\bar{a}, x, j) d\xi$; labor markets clear, i.e., $N_S = \int_{j \in S} x h(\bar{a}, x, j) d\xi$ and $N_U = \int_{j \in U} x h(\bar{a}, x, j) d\xi$; the final goods market clears, i.e., $\int \{\bar{c}(\bar{a}, x, j) + \bar{a}'(\bar{a}, x, j)\} d\xi = F \left( N_S, N_U, \bar{K}_E, \bar{K}_S; \bar{z} \right) + (1 - \delta_E) \bar{K}_E + (1 - \delta_S) \bar{K}_S$; and individual and aggregate behaviors are consistent for all $A^0 \subset \mathcal{A}$ and $X^0 \subset X$, i.e., $\xi' \left( A^0, X^0, j \right) = \int_{A^0 \times X^0} \left\{ \int_{\mathcal{A} \times X} 1_{a' = a(\tilde{a}, x, j)} d\pi(x' | x) d\tilde{a} \right\} d\tilde{a} d\tilde{a}'.

### 4 Skill Premium

The equilibrium skill wage premium is defined as:

$$\omega_{ha} \equiv \frac{w_S N_S}{w_U N_U} / H_S = \left( \frac{w_S}{w_U} \right) \left( \frac{N_S / H_S}{N_U / H_U} \right),$$ (14)

where $H_j$ is the aggregate labor supply of a group $j$, i.e., $H_j = \int h(\bar{a}, x, j) d\xi$ for $j \in \{S, U\}$. The ratio of the market wage for skilled labor to the market wage for unskilled labor, $w_S / w_U$, represents the relative marginal product. The ratio of the aggregate labor input to the aggregate labor supply, $N_j / H_j$, represents the average idiosyncratic productivity of a group $j$, and
thus, the ratio of $N_j / H_j$ between the two groups represents the relative average productivity. The skill wage premium is determined by the product of the relative marginal product and the relative average productivity, and increases with a rise in the relative marginal product and the relative average productivity.

**Effects on skilled and unskilled workers**   When we compare two countries with different tax systems, the difference in the skill wage premium can be written as:

$$\Delta \ln \omega_{ha} = \Delta \ln \left( \frac{w_S N_S}{H_S} \right) - \Delta \ln \left( \frac{w_U N_U}{H_U} \right).$$

(15)

The first term is the difference in the average wage of skilled workers, while the second term is the difference in the average wage of unskilled workers. We refer to the former as the effect on skilled workers and the latter as the effect on unskilled workers. Naturally, the difference in the skill wage premium is proportional to the difference in the average wage of skilled workers, while it is inversely proportional to the difference in the average wage of unskilled workers. The higher skill wage premium is attributable to the higher average wage of skilled workers, the lower average wage of unskilled workers, or both.

**Price and composition effects**   The difference in the skill wage premium can also be decomposed as:

$$\Delta \ln \omega_{ha} = \Delta \ln \left( \frac{w_S}{w_U} \right) + \Delta \ln \left( \frac{N_S / H_S}{N_U / H_U} \right).$$

(16)

The difference in the skill wage premium depends not only on the difference in the relative marginal product of skilled labor but also on the difference in the relative productivity resulting from differences in the tax system. The first term represents the equilibrium effect with respect to a difference in the relative marginal product, while the second term represents the mechanical effect with respect to a difference in the relative average productivity. We refer to the former as the price effect and the latter as the composition effect.
5 Quantitative Assessment

We calibrate the model to the U.S. economy and quantitatively assess the impact of taxes and transfers on the skill wage premium and social welfare. We quantitatively analyze the impact of a change in policy that replaces the U.S. tax system with the Japanese tax system. We outline methods for computing the equilibrium in the model economy in Appendix A.3.

5.1 Parameterization

Table 1 summarizes parameterization for the analysis of the heterogeneous-agents incomplete-markets model. While some parameters are chosen to match specific aggregate targets, other parameters are set outside the model. We follow Trabandt and Uhlig (2011) in setting the consumption tax rate $\tau_c$, the labor income tax rate $\tau_n$, the capital income tax rate $\tau_k$, the ratio of government consumption to output $\tilde{G}$, the ratio of government debt to output $\tilde{B}$, and the growth rate $g$. The fiscal parameters are set at their average values over the years 1995 to 2007.

We follow Krusell, Ohanian, Rios-Rull, and Violante (2000) in setting the depreciation rates of equipment and structures $\delta_E$ and $\delta_S$ and the parameters $\rho$ and $\sigma$ governing the elasticity of substitution between skilled labor and capital and the elasticity of substitution between unskilled labor and the skilled labor-capital composite, respectively. We follow Alonso-Ortiz and Rogerson (2010) in setting the parameters for persistence in productivity $\varrho$ and the variance of idiosyncratic shocks to productivity $\varsigma^2$. We set the share of the skilled population $s$ as equal to the share of people who have a four-year college degree, and hours worked $\bar{h}_j$ as equal to the mean annual hours worked of a group $j$ divided by annual discretionary time ($365 \times 16$), both of which are calculated from the sample of those aged 25 to 60 in the CPS between the years 1995 and 2005.

We calibrate the discount factor $\beta$, the share parameters $\lambda$ and $\mu$ in the production function, and the parameters $\psi_S$ and $\psi_U$ governing the disutility of work to match the capital-output ratio of 2.87, the capital share of output of 38 percent, the skill wage premium of 1.75, the employment rate of 83.5 percent for the skilled population, and the employment rate of 72.6 percent for the unskilled population, respectively. The first two target values are from Trabandt and Uhlig (2011), and the last three target values are from the sample of those aged 25 to 60 in
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<td>0.365</td>
</tr>
<tr>
<td>Disutility of work for skilled (employment rate of skilled, 83.5%; CPS)</td>
<td>2.05</td>
</tr>
<tr>
<td>Disutility of work for unskilled (employment rate of unskilled, 72.6%; CPS)</td>
<td>2.37</td>
</tr>
</tbody>
</table>
the CPS between the years 1995 and 2005.

For the analysis of the representative-agent model, we specify the instantaneous utility function to be: \( U_j(C_{jt}, H_{jt}) = \ln C_{jt} - \psi H_{jt}^{1+\theta} (1 + \theta) \) for \( j \in \{S,U\} \), where \( C_{jt} \) is consumption and \( H_{jt} \) is hours worked in period \( t \). We set the Frisch elasticity at \( \theta = 1 \), this being consistent with the micro and macro literature on labor supply. Following Trabandt and Uhlig (2011), we calibrate \( \psi \) to match the average hours worked of 0.25, and consequently set at \( \psi = 12.6 \). We calibrate a set of parameters \((\beta, \lambda, \mu)\) to match the same targets as those in the heterogeneous-agents incomplete-markets model, and consequently set at \((\beta, \lambda, \mu) = (0.994, 0.545, 0.322)\). The results on the skill wage premium reported below remain almost unchanged regardless of the value of the Frisch elasticity.

By virtue of the calibration procedure, we replicate the target values exactly both in the heterogeneous-agents incomplete-markets model and the representative-agent model. In the heterogeneous-agents incomplete-markets model, we can also replicate the variance of the log wage almost exactly. Although we do not calibrate any parameters to match the variance of the log wage, the predicted value of 0.453 is close to the average value of 0.450 in the CPS between the years 1995 and 2005.

5.2 Labor market implications

We analyze the impact of a change in policy that replaces the U.S. tax system with the Japanese tax system. For this purpose, we characterize the tax system by five fiscal parameters \((\tau_c, \tau_n, \tau_k, \bar{G}, \bar{B})\) and assign different values to all fiscal parameters for the United States and Japan, while holding the values of the other parameters fixed. We set the fiscal parameters in Japan based on the results of Gunji and Miyazaki (2011). Their average values over the years 1995 to 2007 are \( \tau_c = 0.047, \tau_n = 0.288, \tau_k = 0.519, \bar{G} = 0.198, \) and \( \bar{B} = 0.604 \) for Japan, while they are \( \tau_c = 0.05, \tau_n = 0.28, \tau_k = 0.36, \bar{G} = 0.18, \) and \( \bar{B} = 0.63 \) for the United States. The consumption and labor income tax rates are almost the same between the two countries, while the government consumption-output ratio and the government debt-output ratio are not notably different. The key difference in the tax system between the two countries is that the capital income tax rate is significantly higher in Japan than in the United States.
Changes in skill premium  Table 2 shows how the skill wage premium changes when the U.S. tax system is replaced with the Japanese tax system. Replacing the U.S. tax system with the Japanese tax system means raising the size of the tax and transfer system. By doing so, the skill wage premium declines by 13 percentage points from 1.75 to 1.62, which corresponds to 42 percent of the actual difference between the United States and Japan. In addition, we analyze the impact of a change in policy that replaces the U.S. tax rate on capital income with the Japanese tax rate, while holding other fiscal parameters fixed. The skill wage premium then declines even more by 17 percentage points from 1.75 to 1.58, which corresponds to 55 percent of the actual difference between the United States and Japan.

<table>
<thead>
<tr>
<th>Table 2: Tax system and skill premium</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \tau_c, \tau_n, \tilde{G}, \tilde{B} )</td>
</tr>
<tr>
<td>( \tau_k )</td>
</tr>
<tr>
<td>Data</td>
</tr>
<tr>
<td>Heterogeneous agents</td>
</tr>
<tr>
<td>Representative agent</td>
</tr>
</tbody>
</table>

The skill wage premium declines with a rise in the size of the tax and transfer system in the representative-agent model as well as the heterogeneous-agents model. However, the magnitude of the decline is much smaller in the representative-agent model than in the heterogeneous-agents model.

Decomposition of changes in skill premium  To deepen our understanding of the mechanism of the change in the skill wage premium, we decompose changes in the skill wage premium into the effect on skilled workers and the effect on unskilled workers (equation 15) and into the price effect and the composition effect (equation 16). The first and second rows of Table 3 report the log point changes, relative to the U.S. tax system, in the average wage of skilled workers and the average wage of unskilled workers, respectively. When the U.S. tax system is replaced with the Japanese tax system, the decline in the skill wage premium is completely explained by a decrease in the average wage of skilled workers. When the U.S. tax rate on capital income is replaced with the Japanese tax rate, however, 79 percent of the decline in the skill wage premium is attributable to a decrease in the average wage of skilled workers, while the remaining 21 percent is attributable to an increase in the average wage of unskilled workers.
A rise in the tax rate on capital income causes a reduction in the capital stock, which results in a decrease in the average wage of skilled workers who are more complementary to capital, but possibly an increase in the average wage of unskilled workers who are more substitutable with capital.

<table>
<thead>
<tr>
<th>Effect on skilled</th>
<th>Effect on unskilled</th>
<th>Price effect</th>
<th>Composition effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>–8.20 (110.0%)</td>
<td>–0.75 (–10.0%)</td>
<td>–5.33 (71.5%)</td>
<td>–2.12 (28.5%)</td>
</tr>
<tr>
<td>–8.06 (79.0%)</td>
<td>2.14 (21.0%)</td>
<td>–6.28 (61.7%)</td>
<td>–3.91 (38.3%)</td>
</tr>
</tbody>
</table>

The third and fourth rows report the log point changes, relative to the U.S. tax system, in the skill wage premium due to the price effect and the composition effect, respectively. When the U.S. tax system is replaced with the Japanese tax system, the price effect accounts for 72 percent of the decline the skill wage premium, while the composition effect accounts for the remaining 28 percent. When the U.S. tax rate on capital income is replaced with the Japanese tax rate, the price effect accounts for 62 percent, and the composition effect accounts for the remaining 38 percent. A rise in the tax rate on capital income causes a reduction in the relative demand for skilled labor and an increase in the relative supply of skilled labor, which we refer to as the price effect. At the same time, this causes a reduction in the relative average productivity of skilled labor, which we refer to as the composition effect. The price effect and the composition effect work in the same direction to reduce the skill wage premium. The price effect is a significant factor behind the change in the skill wage premium, while the composition effect is also non-negligible. Below we discuss the price effect and the composition effect in more detail.

**Price and composition effects**  Figure 2 illustrates the price effect caused by a rise in the tax rate on capital income in terms of shifts in the relative supply of and demand for skilled labor. In the heterogeneous-agent incomplete-markets model, capital income taxation shifts the relative demand for skilled labor inwards; further, it shifts the relative supply of skilled labor outwards as a result of the income effect arising from redistribution in the form of capital income taxes and transfers. There may be an additional shift in the relative supply of skilled labor as a result
of a change in the interest rate due to a reduction in the capital stock, but such a shift is presumed to be quantitatively negligible.

A change in the composition of workers in the labor market resulting from a rise the tax rate on capital income alters not only the relative supply of skilled labor but also the relative average productivity of skilled labor. The shift in the relative supply causes an equilibrium effect on the skill wage premium, while the change in the relative average productivity causes a mechanical effect. The willingness to work varies across households according to the market wage rate and idiosyncratic shocks to productivity in the heterogeneous-agents incomplete-markets model. Holding other factor fixed, workers are more likely to participate in the labor market, as the market wage and the productivity shock are higher. When the government raises the tax rate on capital income and spends the incremental revenue on transfers to households, unskilled workers are more discouraged to work than skilled workers by the income effect. Among unskilled workers, the lowest-productivity worker is most likely to exit from the labor market. The former effect causes the relative supply of skilled workers to shift outwards, thereby reducing the skill wage premium (Figure 2). The latter effect causes the average productivity of unskilled workers who remain in the labor market to rise, thereby reducing the relative average productivity of skilled workers, and hence, the skill wage premium. Importantly, both effects would be even stronger if the government redistributes transfers to unskilled workers more than to skilled workers. Therefore, the impact of a change in policy that raises the tax rate on capital income presented here can be considered to be conservative.
Representative vs. heterogeneous agents  Given the discussion above, the impact of capital income taxation on the skill wage premium should be greater in the heterogeneous-agents incomplete-markets model than in the representative-agent model for two reasons. First, there is no shift in the relative supply of skilled labor in the representative-agent model (see Appendix A.2 for details). Consequently, the price effect becomes greater in the heterogeneous-agents model than in the representative-agent model. Second, there is no composition effect in the representative-agent model. Since the price effect and the composition effect work in the same direction in the heterogeneous-agents model, the composition effect leads to an additional difference in the impact of capital income taxation between the two models.

Changes in other aggregates  We validate the model by examining its prediction for the capital-output ratio and the ratio of the employment rate of skilled workers to that of unskilled workers. The model predicts that the capital-output ratio is 2.87 under the US tax system, 2.64 under the Japanese tax system, and 2.65 under the Japanese capital income tax rate. The predicted change in the capital-output ratio is consistent with the data. The capital-output ratio in Japan was consistently below 2.5 between the years 1995 and 2005 (Hansen and İmrohoroğlu, 2016), and lower than that in the United States.

The model predicts that the relative employment rate of skilled workers is 1.33 under the US tax system, 1.19 under the Japanese tax system, and 1.23 under the Japanese capital income tax rate. The predicted change in the relative employment rate is also consistent with the data. The relative employment rate in Japan was on average 1.15 in the ESS between the years 1996 and 2006, and lower than that in the United States.

5.3 Welfare implications

We have shown that the skill wage premium significantly declines when the U.S. tax system is replaced with the Japanese tax system. We now evaluate the impact of such a change in tax policy on social welfare. To do so, we use the utilitarian social welfare function, as is common in the literature. We describe the details of the measurement and decomposition of the welfare effect in Appendix A.4.
Social welfare We consider the impact on social welfare of a change in policy that raises the U.S. tax rate on capital income to the Japanese tax rate. To measure the welfare effect, the government consumption-output ratio and the government debt-output ratio are held fixed. Table 4 shows how the consumption-equivalent welfare changes when the U.S. tax rate on capital income is replaced with the Japanese tax rate. We find that such a change in tax policy entails a welfare gain of 1.7 percent in the heterogeneous-agents model. In contrast, it entails a welfare loss of 0.8 percent in the representative-agents model.

<table>
<thead>
<tr>
<th>Table 4: Capital income taxation and social welfare</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tau_c, \tau_n, G, B$</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>Heterogeneous agents</td>
</tr>
<tr>
<td>Welfare</td>
</tr>
<tr>
<td>Skilled</td>
</tr>
<tr>
<td>Unskilled</td>
</tr>
<tr>
<td>Representative agent</td>
</tr>
<tr>
<td>Welfare</td>
</tr>
<tr>
<td>Heterogeneous agents, transition</td>
</tr>
<tr>
<td>Welfare</td>
</tr>
<tr>
<td>Skilled</td>
</tr>
<tr>
<td>Unskilled</td>
</tr>
</tbody>
</table>

The welfare consequences of capital income taxation are completely different in the two models. Capital income taxation results in distortion, which reduces welfare in the representative-agent complete-markets model, but improves welfare in the heterogeneous-agents incomplete-markets model, in which agents tend to work longer and save more than their efficient levels. While it is desirable to reduce the capital income tax rate to zero in the representative-agent model, it is desirable to impose some level of taxes on capital income in the heterogeneous-agents model. Moreover, in the context of a heterogeneous-agents incomplete-markets model, government transfers serve as an insurance against idiosyncratic shocks to productivity, as well as a redistribution to reduce inequality. The distributive impact of taxes and transfers is particularly important in the presence of capital-skill complementarity, because in that case persistent wage differentials exist between skilled workers and unskilled workers.

We measure social welfare by the weighted sum of lifetime utility of all agents. The second and third rows of Table 4 report the welfare effect when measured separately for skilled workers.
and unskilled workers. A rise in the tax rate on capital income entails a welfare loss of 4.9 percent for skilled workers but a welfare gain of 4.5 percent for unskilled workers. One reason for this result is that a rise in the tax rate on capital income results in a reduction in capital stock, which is undesirable for skilled workers who are more complementary to capital but not necessarily so for unskilled workers who are more substitutable with capital. In fact, when the U.S tax rate on capital income is replaced with the Japanese tax rate, the average wage of unskilled workers increases by 2.1 log points, while the average wage of skilled workers decreases by 8.1 log points (Table 2). Another reason is that a rise in the tax rate on capital income is associated with redistribution in the form of transfers. Skilled and wealthier workers pay more taxes, while unskilled and less productive workers benefit more from transfers.

**Decomposition of the welfare effect** To deepen our understanding of the mechanism of the welfare effect, we decompose it into welfare effects attributable to changes in the level and distribution of consumption and leisure. Table 5 shows the extent to which the welfare effect is explained by changes in the level and distribution of consumption and leisure. Capital income taxation reduces the level of consumption but improves the inequality of consumption and the level and inequality of leisure. The welfare loss from a reduction in the level of consumption is greater than the welfare gain from a reduction in the inequality of consumption. The welfare gain from an increase in the level of leisure is substantially greater than the welfare gain from the distribution of leisure due in large part to the linearity of leisure in preferences. In total, the welfare gain from an increase in leisure exceeds the welfare loss from a decline in consumption, when the U.S. tax rate on capital income is replaced with the Japanese tax rate.

<table>
<thead>
<tr>
<th>$\tau_k$, $\tau_n$, $G$, $B$</th>
<th>US $\rightarrow$ JPN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Welfare</td>
<td>0.73%</td>
</tr>
<tr>
<td>Consumption</td>
<td></td>
</tr>
<tr>
<td>level</td>
<td>$-2.71%$</td>
</tr>
<tr>
<td>distribution</td>
<td>0.44%</td>
</tr>
<tr>
<td>Leisure</td>
<td></td>
</tr>
<tr>
<td>level</td>
<td>2.97%</td>
</tr>
<tr>
<td>distribution</td>
<td>0.09%</td>
</tr>
</tbody>
</table>
Welfare along the transition  We have so far measured the welfare effect by comparing the two steady states under different tax systems. This means that the welfare gain or cost in the transition to the new steady state has been ignored in the measurement. When the two steady states are compared before and after a rise in the tax rate on capital income, the welfare gain may be understated because the welfare difference between the two steady states reflects a substantial reduction in the capital stock and the average wage of skilled workers. Along the transition from the initial steady state to the new steady state, however, the capital stock declines gradually, and part of the decline in the capital stock results from an increase in consumption. If the welfare effect is measured after transitional welfare changes are taken into account, the results may change considerably. The last three rows of Table 4 report the welfare effect when the transitional welfare changes for all workers, skilled workers, and unskilled workers, respectively. We consider a once-and-for-all unexpected change in the capital tax rate. The total welfare gain resulting from a rise in the tax rate on capital income increases from 1.7 percent to 2.7 percent.

6 Conclusion

We have analyzed the impact of taxes and transfers on the skill wage premium and social welfare in the context of a heterogeneous-agents incomplete-markets model. We have quantified the extent to which the skill wage premium declines following a rise in the tax rate on capital income in the presence of capital-skill complementarity. The analysis indicates that the skill wage premium declines from 1.75 to 1.62 when the U.S. tax system is replaced with the Japanese tax system, and to 1.58 when only the U.S. tax rate on capital income is replaced with the Japanese tax rate. We have further shown that social welfare can effectively improve as a consequence of such a change in tax policy that reduces persistent wage differentials between skilled workers and unskilled workers.
References


A Appendix

A.1 Skill-specific productivity process

We consider the extended version of the heterogeneous-agents incomplete-markets model, in which the productivity process, as well as the degree of substitution for capital, differ between skilled workers and unskilled workers. We allow both persistence in productivity $\varrho_j$ and the variance of idiosyncratic shocks to productivity $\varsigma_j$ to differ between skilled workers and unskilled workers. Following Krueger and Ludwig (2016), we consider a skill-specific productivity process, in which the persistence is 4.4 percent higher for skilled workers than for unskilled workers, while the variance is 92 percent higher for unskilled workers than for skilled workers. We eventually set at $(\varrho_S, \varsigma^2_S) = (0.9652, 0.1656)$ for skilled workers and $(\varrho_U, \varsigma^2_U) = (0.9244, 0.2295)$ for unskilled workers such that the weighted averages of the respective parameters remain the same. We then recalibrate a set of parameters $(\beta, \lambda, \mu, \psi_S, \psi_U)$ to match the same targets as in the analysis above.

Table 6 shows changes in the skill wage premium and social welfare in the steady state when the U.S. tax rate on capital income is replaced with the Japanese tax rate. We confirm that the main results remain essentially unchanged.

Table 6: Capital income taxation, skill premium, and welfare in the extended model

<table>
<thead>
<tr>
<th>$\tau_c, \tau_n, G, B$</th>
<th>US</th>
<th>US $\rightarrow$ JPN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wage premium</td>
<td>1.75 $\rightarrow$ 1.61</td>
<td></td>
</tr>
<tr>
<td>Effect on skilled</td>
<td>-6.15 (78.7%)</td>
<td></td>
</tr>
<tr>
<td>Effect on unskilled</td>
<td>1.67 (21.3%)</td>
<td></td>
</tr>
<tr>
<td>Price effect</td>
<td>-5.57 (71.2%)</td>
<td></td>
</tr>
<tr>
<td>Composition effect</td>
<td>-2.25 (28.8%)</td>
<td></td>
</tr>
<tr>
<td>Welfare</td>
<td>1.60%</td>
<td></td>
</tr>
<tr>
<td>Skilled</td>
<td>-1.99%</td>
<td></td>
</tr>
<tr>
<td>Unskilled</td>
<td>3.66%</td>
<td></td>
</tr>
</tbody>
</table>

A.2 Representative-agent model

Here, we consider the representative-agent model.
A.2.1 Households

The economy is populated by a continuum of infinitely-lived households. Each household is composed of a unit mass of household members who are either skilled or unskilled indexed by \( j \in \{S, U\} \), and whose preferences are described by \( U_j(C_{jt}, H_{jt}) \), where \( C_{jt} \) is consumption and \( H_{jt} \) is hours worked in period \( t \). We denote \( s \) as the share of household members who are skilled.

We consider a problem in which the representative household maximizes the discounted weighted sum of utility:

\[
\sum_{t=\tau}^{\infty} \beta^{t-\tau} \left[ sU_S(C_{St}, H_{St}) + (1-s) U_U(C_{Ut}, H_{Ut}) \right]
\]  

subject to the budget constraint:

\[
(1 + \tau_c)[sC_{St} + (1-s)C_{Ut}] = (1 - \tau_n)[s w_{St}H_{St} + (1-s) w_{Ut}H_{Ut}]
+ [1 + (1 - \tau_k) r_t] A_t - A_{t+1} + F_t.
\]  

Assets \( A_t \) consist of physical capital and government debt. We specify the instantaneous utility function to be:

\[
U_j(C_{jt}, H_{jt}) = \ln C_{jt} - \psi \frac{H_{jt}^{1+\theta}}{1+\theta}
\text{ for } j \in \{S, U\},
\]

where the parameter \( \psi \) represents the disutility of work, and the parameter \( \theta \geq 0 \) represents the Frisch labor supply elasticity.

Utility maximization entails equating the relative prices with the marginal rates of substitution across goods and time:

\[
C_{St} = C_{Ut} = C_t,
\]

\[
\frac{w_{St}}{w_{Ut}} = \left( \frac{H_{St}}{H_{Ut}} \right)^\theta,
\]

\[
1 + (1 - \tau_k) r_t = \frac{1}{\beta} \left( \frac{C_{t+1}}{C_t} \right).
\]

The consumption and labor income tax rates \( \tau_c \) and \( \tau_n \) do not appear in the utility-maximizing
conditions (20)–(22), while the capital income tax rate $\tau_k$ appears in the intertemporal optimality condition (22). Consumption and labor income taxation influences neither the relative consumption nor the relative labor supply of skilled labor, while capital income taxation influences asset holdings.

A.2.2 Firms

Perfectly competitive firms produce output according to the technology (8).

A.2.3 Government

The government levies proportional taxes on consumption, labor income, and capital income, and spends the tax revenue on government consumption, lump-sum transfers, and interest payments on government debt, according to the balanced budget rule (13).

A.2.4 Equilibrium

The equilibrium of the economy is characterized as follows. Given policies $\{\tilde{G}_t, \tilde{B}_t, \tau_c, \tau_m, \tau_k, \tilde{F}_t\}$ and an initial condition $z_0$, a competitive equilibrium is an allocation $\{\tilde{C}_{St}, \tilde{C}_{Ut}, H_{St}, H_{Ut}, N_{St}, N_{Ut}, \tilde{K}_{Et}, \tilde{K}_{St}\}$ and price system $\{\tilde{w}_{St}, \tilde{w}_{Ut}, r_t\}$ such that: for all $t$, given prices, the allocation solves the household’s problem and the firm’s problem; the government budget is balanced; the capital market clears, i.e., $\tilde{K}_{Et} + \tilde{K}_{St} + \tilde{B}_t = \tilde{A}_t$; labor markets clear, i.e., $N_{St} = sH_{St}$ and $N_{Ut} = (1-s)H_{Ut}$; and the final goods market clears, i.e., $\tilde{C}_t + \tilde{K}_{Et+1} + \tilde{K}_{St+1} = \mathcal{F}(N_{St}, N_{Ut}, \tilde{K}_{Et}, \tilde{K}_{St}; z_t) + (1-\delta_E)\tilde{K}_{Et} + (1-\delta_S)\tilde{K}_{St}$.

A.2.5 Skill premium

The equilibrium skill wage premium is defined as:

$$\omega_{ra} \equiv \frac{w_S}{w_U} = \left( \frac{1-s}{s} \frac{N_S}{N_U} \right)^{\theta}. \quad (23)$$

The skill wage premium decreases with a rise in the share of the skilled population and increases with a rise in the relative demand for skilled labor. When we compare two countries with the
same share of the skilled population but different tax systems, the difference in the skill wage premium is:

\[
\Delta \ln (\omega_{ra}) = \theta \Delta \ln \left( \frac{N_S}{N_U} \right). \tag{24}
\]

The cross-country difference in the skill wage premium is proportional to the difference in the relative demand for skilled labor resulting from differences in the tax system.

### A.3 Numerical algorithm

We describe methods for computing the equilibria in the heterogeneous-agents incomplete-markets model.

**Steady state** We compute the steady-state equilibrium allocation in the heterogeneous-agents incomplete-markets model by extending the numerical algorithm in Aiyagari and McGrattan (1998) and Flodén and Lindé (2001), who build upon the algorithm of Huggett (1993) and Aiyagari (1995).

1. Discretize the state space \((\bar{a}, x, j)\), and compute the transition probability \(\pi (x'|x)\) using the Tauchen (1986) method.

2. Set a guess for \(\{\tilde{K}_E, N_S, \tilde{z}\}\). Compute \(\tilde{K}_S\) from (11) and (12).

3. Given \(\{\tilde{K}_E, \tilde{K}_S, N_S, \tilde{z}\}\), compute \(\tilde{w}_S\) from (9), \(r\) from (11), \(N_U\) from (8), \(\tilde{w}_U\) from (10), and aggregate consumption \(\tilde{C}\) from the goods market clearing condition. Given \(\{\tilde{G}, \tilde{B}, \tau_c, \tau_n, \tau_k\}\), compute \(\tilde{F}\) from (13).

4. Solve for the beginning-of-period value function \(V(\bar{a}, x, j)\).

   (a) Set a guess for \(V(\bar{a}, x, j)\).

   (b) Update the value function using the Bellman equations (5) and (6) until convergence.

   Given the value function, obtain the decision rules \(\{\tilde{c}(\bar{a}, x, j), h(\bar{a}, x, j), \tilde{a}(\bar{a}, x, j)\}\).

5. Compute the stationary distribution \(\xi(\bar{a}, x, j)\).

   (a) Set a guess for \(\xi(\bar{a}, x, j)\).
(b) Update the distribution by weighting the transition probability according to the distance from the optimal asset holdings to the two adjacent grid points, until convergence.

6. Update \( \{\widetilde{K}_E, N_S, \widetilde{z}\} \). Repeat steps 2 to 5 until convergence.

**Transitional dynamics** We compute the transition path from the initial steady state to the new steady state as follows:

1. Compute the initial steady state. Assume that the economy converges to the new steady state after 100 periods, and compute the new steady state.

2. Set a guess for the transition path of \( \{\widetilde{K}_E, \widetilde{K}_S, N_S, \widetilde{z}\}_t=0^{100} \). Given this path, compute the transition path of \( \{\widetilde{w}_S, \widetilde{w}_U, r, N_U, \widetilde{C}_t, \widetilde{F}_t\}_t=0^{100} \).

3. Solve the agent’s problem backwards from the last period to the first period, and obtain the decision rules.

4. Given the decision rules, simulate the economy forward from the first period to the last period.

5. Update \( \{\widetilde{K}_E, \widetilde{K}_S, N_S, \widetilde{z}\}_t=0^{100} \). Repeat steps 2 to 5 until convergence.

**A.4 Welfare measurement**

We describe the measurement and decomposition of the welfare effect of a change in policy.

**Social welfare** Social welfare can be defined as the weighted sum of the lifetime utility of all agents, which depends on consumption \( c_j \) and leisure, defined as \( \ell_j = 1 - h_j \):

\[
\Upsilon_m = \int_{\{j=S,U\}} V^m(a, x, j) d\xi^m + \frac{\ln Y_0^m}{1-\beta} + \frac{\beta \ln (1+g)}{(1-\beta)^2} \\
= \int_{\{j=S,U\}} \left\{ \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[ \ln c^m - \psi_j (1-\ell^m) \right] \right\} d\xi^m + \frac{\ln Y_0^m}{1-\beta} + \frac{\beta \ln (1+g)}{(1-\beta)^2} \quad \text{for } m \in \{0,1\},
\]
where \( m = 0 \) and \( m = 1 \) represent the pre-reform steady state and the post-reform steady state, respectively, and \( Y_0 \) is the initial output. The welfare consequence of a change in the tax rate can be expressed as the percentage change in consumption, denoted by \( \sigma \), required to leave the agents indifferent between the two equilibrium allocations:

\[
\int_{j=S,U} \left\{ \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[ \ln \left( 1 + (1 + \sigma)c^0 \right) - \psi_j \left( 1 - \ell^0 \right) \right] \right\} d\xi^0 + \frac{\ln Y_0}{1 - \beta} = \int_{j=S,U} \left\{ \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[ \ln c^1 - \psi_j \left( 1 - \ell^1 \right) \right] \right\} d\xi^1 + \frac{\ln Y_1}{1 - \beta}. \tag{26}
\]

The welfare effect of a policy reform can then be measured by:

\[
\sigma = \exp \left[ (1 - \beta) (Y_1 - Y_0) \right] - 1. \tag{27}
\]

The welfare effect can be decomposed into the portion attributable to a change in consumption and the portion attributable to a change in leisure. Each of the two effects can be further decomposed into the portion attributable to a change in the level of consumption or leisure and the portion attributable to a change in the distribution of consumption or leisure:

\[
1 + \sigma = (1 + \sigma_c) (1 + \sigma_\ell) = \left( 1 + \sigma_c^{\text{level}} \right) \left( 1 + \sigma_c^{\text{dist}} \right) \left( 1 + \sigma_\ell^{\text{level}} \right) \left( 1 + \sigma_\ell^{\text{dist}} \right). \tag{28}
\]

Or approximately, \( \sigma \approx \sigma_c^{\text{level}} + \sigma_c^{\text{dist}} + \sigma_\ell^{\text{level}} + \sigma_\ell^{\text{dist}} \). Below we describe the details of the welfare decomposition.

**Decomposition of the welfare effect** We decompose the welfare effect into the portion attributable to a change in consumption and the portion attributable to a change in leisure, i.e., \( 1 + \sigma = (1 + \sigma_c)(1 + \sigma_\ell) \), and further decompose each of the two effects into the portion attributable to a change in the level of consumption or leisure and the portion attributable to a change in the distribution of consumption or leisure, i.e., \( 1 + \sigma_c = (1 + \sigma_c^{\text{level}})(1 + \sigma_c^{\text{dist}}) \) and \( 1 + \sigma_\ell = (1 + \sigma_\ell^{\text{level}})(1 + \sigma_\ell^{\text{dist}}) \). Given the specification of preferences, it is possible to derive a closed-form expression for each welfare effect. We first derive \( 1 + \sigma_\ell \) by the linearity of leisure in the utility function, and calculate \( 1 + \sigma_c \) as the residual, i.e., \( 1 + \sigma_c = (1 + \sigma) / (1 + \sigma_\ell) \). We
then derive $1 + \omega^\text{level}_c$ and $1 + \omega^\text{level}_\ell$, and calculate $1 + \omega^\text{dist}_c$ and $1 + \omega^\text{dist}_\ell$ as the residuals, i.e.,

$$
\omega^\text{dist}_c = \frac{(1 + \omega_c)}{(1 + \omega^\text{level}_c)} - 1 \quad \text{and} \quad \omega^\text{dist}_\ell = \frac{(1 + \omega_\ell)}{(1 + \omega^\text{level}_\ell)} - 1.
$$

Below we provide the description of $\omega_\ell$, $\omega^\text{level}_c$, and $\omega^\text{level}_\ell$.

We denote $L_j$ as the aggregate leisure of a group $j$, and define the aggregate leisure as $L = L_S + L_U$. We denote by the superscripts 0 and 1 the pre-reform steady state and the post-reform steady state, respectively. The welfare effect attributable to a change in leisure can be obtained by changing leisure while holding consumption constant.

$$
\omega_\ell = \exp \left[ \psi_S \left( L^1_S - L^0_S \right) - \psi_U \left( L^1_U - L^0_U \right) \right] - 1
$$

(29)

The welfare effect attributable to a change in the level of leisure can be described by changing the level of leisure while holding the distribution and consumption constant.

$$
\omega^\text{level}_\ell = \exp \left[ \left( \psi_S L^0_S + \psi_U L^0_U \right) \left( \frac{L^1_L}{L^0_L} - 1 \right) \right] - 1.
$$

(30)

Similarly, the welfare effect attributable to a change in the level of consumption can be obtained by changing the level of consumption while holding the distribution and leisure constant.

$$
\omega^\text{level}_c = \frac{C^1}{C^0} - 1.
$$

(31)

The ratio of $C^1$ to $C^0$ is constant because the growth rate is invariant with respect to tax rates.