

Slavik, Ctirad; Yazici, Hakki

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## Determinants of Wage and Earnings Inequality in the United States

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# Determinants of Wage and Earnings Inequality in the United States

Ctirad Slavík and Hakki Yazici\*

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PRELIMINARY

**Extended Abstract.** The U.S. wage and earnings distributions display significantly higher levels of inequality today compared to the late 1960's. The aim of this paper is twofold. First, we want to assess to what extent the observed changes in inequality can be explained by a model that incorporates the technology-education race model of Tinbergen (1974) into a standard incomplete markets model that macroeconomists use to study inequality. Second, we want to use this model to decompose the changes in the skill premium and in overall inequality into four components: skill-biased technical change, increase in the relative supply of skilled workers, increase in residual wage volatility, and changes in tax policy.

We construct an incomplete markets model with capital-skill complementarity in which the wage distribution responds endogenously to technological changes. That is, technological advancements - modeled as a decline in the price of equipments - increase the amount of equipments in the economy which increases the skill premium endogenously. We calibrate the deep parameters of the model to late 1960's U.S. economy and find that the model matches well the inequality measures in the data. We find that our model overestimates somewhat the changes in both the skill premium and overall measures of inequality between the 1960's and the 2000's.

We then decompose the change in inequality into changes in technology, relative supply of skilled workers, residual wage risk, and taxes. In line with Tinbergen (1974)'s technology-education race theory, we find that the skill premium is most significantly affected by the changes in technology and supply of skilled workers. We also identify a mechanism not previously analyzed in the literature: an increase in residual wage risk leads to higher precautionary savings and thus to higher levels of aggregate capital. Due to capital-skill complementarities in the production function, this leads to an increase in the skill premium and thus to a further increase in inequality.

*JEL classification:* E25, J31.

*Keywords:* Skill premium, wage inequality, earnings inequality, capital-skill complementarity, skill-biased technical change.

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\*Ctirad Slavík, Goethe University Frankfurt, email: slavik@econ.uni-frankfurt.de, Hakki Yazici, Sabanci University (Istanbul), email: hakkiyazici@sabanciuniv.edu.

# 1 Introduction

Wages and earnings in the United States are significantly more unequal today than they were fifty years ago. This is true independent of whether one considers educational wage differentials such as skill premium (the ratio of the average wage of the college educated people to the average wage of those without college education) or measures of overall inequality such as the Gini coefficient. The skill premium has gone up from about 1.55 in the late 1960's to 1.80 in the 2000's. The Gini coefficient of the wage distribution has gone up from 0.28 to 0.37. Inequality measured in terms of earnings has followed a similar pattern. The earnings Gini has gone up from 0.35 to 0.42.<sup>1</sup>

The aim of this paper is twofold. First, we want to see how much of the observed changes in these measures of inequality can be explained by a model that incorporates the technology-education race model of Tinbergen (1974) into a standard incomplete markets model that macroeconomists use to study inequality. Second, we want to use this model to decompose the changes in the skill premium and in overall inequality into four different components: one due to skill-biased technical change, one part that is due to the increase in the relative supply of skilled workers, another part that is due to the increasing residual wage volatility, and a fourth part that is due to changes in tax policy.

Specifically, this paper builds an infinite horizon macroeconomic model with heterogeneous agents with the following features. First, agents are either skilled or unskilled, and the skill type is permanent. Second, within each skill group, agents are subject to idiosyncratic labor productivity shocks. Third, there are two types of capital, structure capital and equipment capital, and the production function features a higher degree of complementarity between equipment capital and skilled labor than between equipment capital and unskilled labor, as documented empirically for the U.S. economy by Krusell, Ohanian, Ríos-Rull, and Violante (2000). This production function together with declining equipment prices induce skill-biased technical change. There is also a government in the model which uses linear

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<sup>1</sup>These numbers are taken from Heathcote, Perri, and Violante (2010).

taxes on capital income and consumption, and a non-linear labor income tax schedule to finance government consumption and repay debt. We solve for the stationary competitive equilibrium of this model and calibrate the model parameters to the late 1960's of the U.S. economy. Then, we feed in the 2000's observed values of the equipment prices, the relative supply of skilled labor, residual wage volatility, and capital and labor taxes.<sup>2</sup> We compute the steady-state of this economy, and compare the 2000's economy to the 1960's economy to see how much of the observed change in inequality the model is able to replicate.

Before discussing the model's performance in matching the changes in inequality, we describe how well the calibrated model fits 1967 U.S. economy. Even though the model calibration only targets the skill premium for 1967, the model is successful in terms of matching wage and earnings Gini coefficients. The Gini coefficient for wages in the data is 0.28 whereas the model generates 0.26. Similarly, the Gini for earnings is 0.35 while the model delivers 0.37.

As for explaining the changes in inequality, we find that the model overestimates somewhat the increase in both the skill premium and the measures of overall inequality. Skill premium in the data increases by 16%, from 1.55 to 1.8 whereas in the model it increases by 21%, from 1.55 to about 1.88. The Gini coefficient of the wage distribution increases by 32% in the data while the model predicts this number to be 50%. Finally, earnings Gini also increases more in the model than it is in the data: 20% vs. 36%.

Next, we use the model to decompose the changes in inequality into four components. Regarding the skill premium, we find that, in line with the technology-race model, skill-biased technical change and the change in relative supply of skilled workers are the two most important changes in terms of affecting skill premium. We also identify a mechanism not previously analyzed in the literature, which links the rise in within group inequality (residual wage risk) to the rise in between group inequality (skill premium).<sup>3</sup> We find that the increase

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<sup>2</sup>The current version treats the supply of skills as exogeneous. We are working on a version of the model with endogeneous education decisions. We believe that this is important, because changes in policies will affect people's incentives to acquire education.

<sup>3</sup>The literature has typically treated these as two separate economic phenomena. See the discussion in

in residual wage risk also substantially contributes to the rise of the skill premium. If the increase in residual wage risk was the only change between 1960's and 2000's, the skill premium would have gone up from 1.55 to 1.67. That is, in our model, the rise of residual wage risk accounts for 37% of the overall rise in the skill premium. To the best of our knowledge, the idea that a rise in residual wage inequality can increase between-group wage inequality is novel. Intuitively, this happens because higher risk leads to higher precautionary savings, and thus, to higher levels of aggregate capital. Due to capital-skill complementarities in the production function, this leads to an increase in the skill premium. We also find that the observed increase in the progressivity of labor income taxes has decreased the skill premium while the observed changes in capital taxes have increased it. In both cases, though, the effect on skill premium is modest.

Regarding the decomposition of the overall change in inequality, we find that the observed increase in productivity risk is the most significant contributor to the rise of the wage and earnings Gini coefficients. Interestingly, skill-biased technical change contributes almost at the same magnitude. The changes in relative supply of skilled labor and taxes have only modest effects on overall inequality measures.

**Related Literature.** This paper is related to two different strands of literature. First, it relates to a growing literature that aims to explain the evolution of skill premium in the United States in the last fifty years. Krusell, Ohanian, Ríos-Rull, and Violante (2000) estimate a production function with equipment and structure capital and skilled and unskilled labor, and use this production function to explain the evolution of skill premium between 1965 and 1992. Buera, Kaboski, and Rogerson (2015) analyzes the role of structural change on the change of skill premium between 1977 and 2005. He and Liu (2008) tries to match the evolution of skill premium between 1949 and 2000 using a model that features skill-biased technical change along with endogenous skill supply. They model skill-biased

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Guvenen and Kuruscu (2012), whose main contribution is to provide a model in which both within group inequality and between group inequality are linked through a single driving force, a particular version of skilled biased technical change.

technical change using the production function estimated by Krusell, Ohanian, Ríos-Rull, and Violante (2000) and the decline in equipment capital prices. He (2012) also studies the effects of skill-biased technical change, but this time in a model where the demographic change known as the baby boom and the baby bust is also present. He finds that technical change is the key element driving the skill premium in the postwar U.S. economy and that the demographic change is quantitatively not important for skill premium. This paper differs from this literature mainly because it models residual wage risk. This is an important distinction since modeling risk allows us to analyze the changes in skill premium and overall inequality in a unified framework which allows us to study the interactions between the two.

This paper is also related to the literature that aims to identify the main causes of the evolution of the wage distribution in the United States. Goldin and Katz (2008) is a monumental piece that discusses the evolution of the U.S. wage structure through the lens of Tinbergen (1974)'s model of the race between education and technology. Autor, Katz, and Kearney (2006) explains the polarization of the of the U.S. labor market using the routinization hypothesis. Heckman, Lochner, and Taber (1998), Guvenen and Kuruscu (2010), Guvenen and Kuruscu (2012), and Guvenen, Kuruscu, and Ozkan (2014) focus on human capital accumulation and labor income taxation as important determining factors of the change in wage inequality. Unlike the current paper, none of the papers in this literature models skill-biased technical change endogenously. Modeling skill-biased technical change endogenously is important especially when it comes to counterfactual policy analysis.

## 2 Model

We consider an infinite horizon growth model similar to the one described in Slavík and Yazici (2015) with two types of capital (structures and equipments), two types of labor (skilled and unskilled), consumers, a firm, and a government.

**Endowments and Preferences.** There is a continuum of measure one of agents who live for infinitely many periods. In each period, they are endowed with one unit of time. Ex-ante, they differ in their skill levels: they are born either skilled or unskilled,  $i \in \{u, s\}$ . Skilled agents can only work in the skilled labor sector and unskilled agents only in the unskilled labor sector. The skill types are exogeneously given and permanent in the current version of the paper.<sup>4</sup> The total mass of the skilled agents is denoted by  $\pi_s$ , the total mass of the unskilled agents is denoted by  $\pi_u$ . In the quantitative analysis, skill types correspond to educational attainment at the time of entering the labor market. Agents who have college education or above are classified as skilled agents and the rest of the agents are classified as unskilled agents. In Section 4 we analyze the effects of changes in the skilled-to-unskilled ratio.

In addition to heterogeneity between skill groups, we model heterogeneity within each skill group by assuming that agents face idiosyncratic labor productivity shocks over time. The productivity shock, denoted by  $z$ , follows a Markov chain with states  $Z = \{z_1, \dots, z_I\}$  and transitions  $\Pi(z'|z)$ . We parameterize the skill process in Section 3 taking into account that it has changed between the 1960's and the 2000's. An agent of skill type  $i$  and productivity level  $z$  who works  $l$  units of time produces  $l \cdot z$  units of effective  $i$  type of labor. As a result, her wage per unit of time is  $w_i \cdot z$ , where  $w_i$  is the wage per effective unit of labor in sector  $i$ .

Preferences over sequences of consumption and labor,  $(c_{i,t}, l_{i,t})_{t=0}^{\infty}$ , are defined using a separable utility function

$$E\left(\sum_{t=0}^{\infty} \beta^t u(c_{i,t}) - v(l_{i,t})\right),$$

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<sup>4</sup>We are currently working on an extension of the model with an explicit education choice.

where  $\beta$  is the time discount factor. The unconditional expectation,  $E$  is taken with respect to the stochastic processes governing the idiosyncratic labor shock. There are no aggregate shocks.

**Technology.** There is a constant returns to scale production function:  $Y = F(K_s, K_e, L_s, L_u)$ , where  $K_s$  and  $K_e$  refer to aggregate structure capital and equipment capital and  $L_s$  and  $L_u$  refer to aggregate effective skilled and unskilled labor, respectively. We also define a function  $\tilde{F}$  that gives the total wealth of the economy:  $\tilde{F} = F + (1 - \delta_s)K_s + (1 - \delta_e)K_e$ , where  $\delta_s$  and  $\delta_e$  are the depreciation rates of structure and equipment capital, respectively.

The key feature of the technology that we use in our quantitative analysis is equipment-skill complementarity, which means that the degree of complementarity between equipment capital and skilled labor is higher than that between equipment capital and unskilled labor. This implies that an increase in the stock of equipment capital decreases the ratio of the marginal product of unskilled labor to the marginal product of skilled labor. In a world with competitive factor markets, this implies that the skill premium, defined as the ratio of skilled to unskilled wages, is increasing in equipment capital. Structure capital, on the other hand, is assumed to be neutral in terms of its complementarity with skilled and unskilled labor. These assumptions on technology are in line with the empirical evidence provided by Krusell, Ohanian, Ríos-Rull, and Violante (2000).

Finally, we assume that the one unit of the general consumption good can be converted into one unit of structure or into  $\frac{1}{q}$  unit of equipment capital. This means the relative price of structure capital and equipment capital in terms of the general consumption good is 1 and  $q$ , respectively. In Section 4 we analyze the implications of skill-biased technical change, i.e., a drop in  $q$ .

**Production.** There is a representative firm which, in each period, hires the two types of labor and rents the two types of capital to maximize profits. In any period  $t$ , its maximization



problem reads:

$$\max_{K_{s,t}, K_{e,t}, L_{s,t}, L_{u,t}} F(K_{s,t}, K_{e,t}, L_{s,t}, L_{u,t}) - r_{s,t}K_{s,t} - r_{e,t}K_{e,t} - w_{s,t}L_{s,t} - w_{u,t}L_{u,t},$$

where  $r_{s,t}$  and  $r_{e,t}$  are the rental rates of structure and equipment capital, and  $w_{u,t}$  and  $w_{s,t}$  are the wages rates paid to unskilled and skilled effective labor in period  $t$ .

**Asset Market Structure.** There is a single risk free asset which has a one period maturity. Consumers can save using this asset but are not allowed to borrow. Every period total savings by consumers must be equal to total borrowing of the government plus the total capital stock in the economy.

**Government.** The government uses linear consumption taxes every period  $\{\tau_{c,t}\}_{t=0}^{\infty}$  and linear taxes on capital income net of depreciation. The tax rates on the two types of capital can, in general, be different. Let  $\{\tau_{s,t}\}_{t=0}^{\infty}$  and  $\{\tau_{e,t}\}_{t=0}^{\infty}$  be the sequences of tax rates on structure and equipment capital. It is irrelevant for our analysis whether capital income is taxed at the consumer or at the corporate level. We assume without loss of generality that all capital income taxes are paid at the consumer level. The government taxes labor income using a sequence of possibly non-linear functions  $\{T_t(y)\}_{t=0}^{\infty}$ , where  $y$  is labor income and  $T_t(y)$  are the taxes paid by the consumer. This function allows us to model the progressivity of the U.S. labor income tax code. The changes in labor tax progressivity is one of the factors whose implications for economic inequality we study in Section 4. The government uses taxes to finance a stream of expenditure  $\{G_t\}_{t=0}^{\infty}$  and repay government debt  $\{D_t\}_{t=0}^{\infty}$ .

In our quantitative analysis we focus on the comparison of stationary equilibria where one stationary equilibrium corresponds to the 1960's and another one to the 2000's. For that reason, instead of giving a general definition of competitive equilibrium, here we only define stationary recursive competitive equilibria. In order to define a stationary equilibrium, we assume that policies (government expenditure, debt and taxes) do not change over time.

Before we define a stationary equilibrium formally, notice that, in the absence of aggregate

productivity shocks, the returns to saving in the form of the two capital types are certain. The return to government bond is also known in advance. Therefore, in equilibrium all three assets must pay the same after-tax return, i.e.,  $R = 1 + (r_s - \delta_s)(1 - \tau_s) = \frac{q_e + (r_e - q_e \delta_e)(1 - \tau_e)}{q_e}$ , where  $R$  refers to the stationary return on the bond holdings. As a result, we do not need to distinguish between saving through different types of assets in the consumer's problem. We denote consumers' asset holdings by  $a$ .

**Stationary Recursive Competitive Equilibrium (SRCE).** SRCE is two value functions  $V_u, V_s$ , policy functions  $c_u, c_s, l_u, l_s, a'_u, a'_s$ , the firm's decision rules  $K_s, K_e, L_s, L_u$ , government policies  $\tau_c, \tau_s, \tau_e, T(\cdot), D, G$ , two distributions over productivity-asset types  $\lambda_u(z, a), \lambda_s(z, a)$  and prices  $w_u, w_s, r_s, r_e, R$  such that

1. The value functions and the policy functions solve the consumer problem given prices and government policies, i.e., for all  $i \in \{u, s\}$ :

$$V_i(z, a) = \max_{(c_i, l_i, a'_i) \geq 0} u(c_i) - v(l_i) + \beta \sum_{z'} \Pi_i(z'|z) V_i(z', a'_i) \quad \text{s.t.}$$

$$(1 + \tau_c)c_i + a'_i \leq w_i z l_i - T(w_i z l_i) + R a,$$

where  $R = 1 + (r_s - \delta_s)(1 - \tau_s) = \frac{q_e + (r_e - q_e \delta_e)(1 - \tau_e)}{q_e}$  is the after-tax asset return.

2. The firm solves:

$$\max_{K_s, K_e, L_s, L_u} F(K_s, K_e, L_s, L_u) - r_s K_s - r_e K_e - w_s L_s - w_u L_u.$$

3. The distribution  $\lambda_i$  is stationary for each type, i.e.  $\forall i : \lambda'_i(z, a) = \lambda_i(z, a)$ . This means:

$$\lambda_i(\bar{z}, \bar{a}) = \int_z \int_{a: a'_i(z, a) = \bar{a}} \lambda_i(z, a) \cdot da \cdot d\Pi_i(\bar{z}|z).$$

4. Markets clear:

$$\begin{aligned} \sum_i \pi_i \int_z \int_a a \cdot d\lambda_i(z, a) &= K_s + K_e + D, \\ \pi_s \int_z \int_a z l_s(z, a) \cdot d\lambda_s(z, a) &= L_s, \\ \pi_u \int_z \int_a z l_u(z, a) \cdot d\lambda_u(z, a) &= L_u, \\ C + G + K_s + K_e &= \tilde{F}(K_s, K_e, L_s, L_u), \end{aligned}$$

where  $C = \sum_{i=u,s} \pi_i \int_z \int_a c_i(z, a) \cdot d\lambda_i(z, a)$  denotes aggregate consumption.

5. Government budget constraint is satisfied.

$$RD + G = D + \tau_c C + \tau_e (r_e - \delta_e) K_e + \tau_s (r_s - \delta_s) K_s + T_{agg},$$

where  $T_{agg} = \sum_{i=u,s} \pi_i \int_z \int_a T(w_i z l_i(z, a)) \cdot d\lambda_i(z, a)$  denotes aggregate labor tax revenue.

### 3 Calibration

We calibrate the deep parameters of the model by assuming that the SRCE of our model economy under 1960's technology, relative supply of skilled workers, residual wage risk, and taxes coincides to the U.S. economy in the 1960's. We first fix a number of parameters to values from the data or from the literature. These parameters are summarized in Table 1. We then calibrate the remaining parameters so that the SRCE matches the U.S. data in 1967 along selected dimensions. Our calibration procedure is summarized in Table 2.

One period in our model corresponds to one year. We assume that the period utility function takes the form

$$u(c) - v(l) = \frac{c^{1-\sigma}}{1-\sigma} - \phi \frac{l^{1+\gamma}}{1+\gamma}.$$

In the benchmark case, we use  $\sigma = 1$  and  $\gamma = 1$ . These are within the range of values that have been considered in the literature. We calibrate  $\phi$  to match the average labor supply.

We further assume that the production function takes the same form as in Krusell, Ohanian, Ríos-Rull, and Violante (2000):

$$Y = F(K_s, K_e, L_s, L_u) = K_s^\alpha \left( \nu [\omega K_e^\rho + (1 - \omega) L_s^\rho]^{\frac{\eta}{\rho}} + (1 - \nu) L_u^\eta \right)^{\frac{1-\alpha}{\eta}}. \quad (1)$$

Krusell, Ohanian, Ríos-Rull, and Violante (2000) estimate  $\alpha, \rho, \eta$ , and we use their estimates.  $\rho$  controls the degree of complementarity between equipment capital and skilled labor while  $\eta$  controls the degree of complementarity between equipment capital and unskilled labor. Krusell, Ohanian, Ríos-Rull, and Violante (2000)'s estimates for these two parameters imply that there is equipment-skill complementarity. Krusell, Ohanian, Ríos-Rull, and Violante (2000) do not estimate  $\omega$  and  $\rho$ . We calibrate these parameters to U.S. data, as we explain in detail below. We also assume that the price of equipment capital  $q = 1$  for the benchmark 1967 calibration.

We take government consumption-to-output ratio to be 16%, which is close to the average ratio in the United States during the period 1970 – 2012, as reported in the National Income and Product Accounts (NIPA) data. To approximate the progressive U.S. labor tax code, we follow Bakis, Kaymak, and Poschke (2014) and assume that tax liability given labor income  $y$  is defined as:

$$T(y) = \bar{y} \left[ \frac{y}{\bar{y}} - \lambda \left( \frac{y}{\bar{y}} \right)^{1-\tau_l} \right],$$

where  $\bar{y}$  is the mean labor income in the economy,  $1 - \lambda$  is the average tax rate of a mean income individual, and  $\tau_l$  controls the progressivity of the tax code. Using PSID data, Bakis, Kaymak, and Poschke (2014) estimate  $\tau_l = 0.08$  for the late 1960's and early 1970's. We use their estimate and calibrate  $\lambda$  to clear the government budget.

Auerbach (1983) documents that the effective tax rates on structure capital and equipment capital have historically differed at the firm level. Specifically, he computes the effective

Table 1: Benchmark Parameters for 1967

Parameter	Symbol	Value	Source
Preferences			
Relative risk aversion parameter	$\sigma$	1	
Inverse Frisch elasticity	$\gamma$	1	
Technology			
Structure capital depreciation rate	$\delta_s$	0.056	GHK
Equipment capital depreciation rate	$\delta_e$	0.124	GHK
Share of structure capital in output	$\alpha$	0.117	KORV
Measure of elasticity of substitution between equipment capital $K_e$ and unskilled labor $L_u$	$\eta$	0.401	KORV
Measure of elasticity of substitution between equipment capital $K_e$ and skilled labor $L_s$	$\rho$	-0.495	KORV
Relative supply of skilled workers in 1967	$p_s/p_u$	0.1356	CPS
Productivity			
Productivity persistence in 1967	$\rho^{67}$	0.8253	HSV
Productivity volatility in 1967	$var(\varepsilon^{67})$	0.0653	HSV
Government polices			
Labor tax progressivity in 1967	$\tau_l$	0.08	BKP
Overall tax on structure capital income	$\tau_s$	0.5665	Auerbach (1983)
Overall tax on equipment capital income	$\tau_e$	0.4985	Auerbach (1983)
Consumption tax	$\tau_c$	0.05	MTR
Government consumption	$G/Y$	0.16	NIPA
Government debt	$D/Y$	0.6	St. Louis FED

This table reports the benchmark parameters that we take directly from the literature or the data. The acronyms BKP, GHK, HSV, KORV, KL, and MTR stand for Bakis, Kaymak, and Poschke (2014), Greenwood, Hercowitz, and Krusell (1997), Heathcote, Storesletten, and Violante (2014), Krusell, Ohanian, Ríos-Rull, and Violante (2000), Krueger and Ludwig (2013), and Mendoza, Razin, and Tesar (1994) respectively. NIPA stands for the National Income and Product Accounts.

corporate tax rate on structure capital and equipment capital from 1953 to 1983. According to his estimates, in the 1960's, the average tax rate on equipment capital was approximately 41% while the average tax on structures was approximately 49%. We further assume that the capital income tax rate at the consumer level is 15%, which approximates the U.S. tax code. This implies an overall tax on structure capital of  $\tau_s = 1 - 0.85 \cdot (1 - 0.49) = 56.65\%$  and an overall tax on equipment capital of  $\tau_e = 1 - 0.85 \cdot (1 - 0.41) = 49.85\%$ . Following Mendoza, Razin, and Tesar (1994) we assume that the consumption tax  $\tau_c = 5.0\%$ . Finally, we assume a government debt of 60% of GDP.

The ratio of skilled to unskilled agents,  $p_s/p_u$  is calculated to be 0.1356 using Current Population Survey (CPS) 1967. We consider educational attainment for people of 25 years and older who have earnings. To be consistent with Krusell, Ohanian, Ríos-Rull, and Violante (2000), we define skilled people as those who have at least 16 years of schooling (college degree with 4 years).

We assume that the processes for  $z$  is identical for the two types of agents. Thus, skill premium in the model economy is given by  $w_s/w_u$ . We normalize the mean level of the idiosyncratic labor productivity shock to one, i.e., set  $E[z] = 1$ . Further, we assume that  $\log z_{t+1} = \rho \log z_t + \varepsilon_t$ . We specify the parameters of this process following Heathcote, Storesletten, and Violante (2010). This gives us  $\rho^{67} = 0.8253$  and  $var(\varepsilon_t^{67}) = 0.0653$ . The details of the parameter specification are given in Appendix A. We approximate these processes by finite number Markov chains using the Rouwenhorst method described in Kopecky and Suen (2010).

There are still five parameter values left to be assigned: these are the two production function parameters,  $\omega$  and  $\nu$ , which govern the income shares of equipment capital, skilled labor and unskilled labor, the labor disutility parameter  $\phi$ , the discount factor  $\beta$ , and the parameter governing the overall level of taxes in the tax function,  $\lambda$ . We calibrate  $\omega$  and  $\nu$  so that (i) the labor share equals 2/3 (approximately the average labor share in 1970 – 2010 as reported in the NIPA data) and (ii) the skill premium  $w_s/w_u$  equals 1.55 (as reported by

Table 2: Benchmark Calibration Procedure for 1967

Parameter	Symbol	Value	Target	Data and SRCE	Source
Production parameter	$\omega$	0.8287	Labor share	2/3	NIPA
Production parameter	$\nu$	0.4179	Skill premium $\frac{w_s}{w_u} - 1$ in 1967	55%	HPV
Disutility of labor	$\phi$	11.42	Labor supply	1/3	
Discount factor	$\beta$	0.9806	Capital-to-output ratio	2.9	NIPA, FAT
Tax function parameter	$\lambda$	0.8606	Gvt. budget balance		

This table reports our benchmark calibration procedure. The production function parameters  $\nu$  and  $\omega$  control the income share of equipment capital, skilled and unskilled labor in output. The tax function parameter  $\lambda$  controls the labor income tax rate of the mean income agent. Relative wealth refers to the ratio of the average skilled to average unskilled agents' asset holdings. The acronym HPV stands for Heathcote, Perri, and Violante (2010). NIPA stands for the National Income and Product Accounts, and FAT stands for the Fixed Asset Tables.

Heathcote, Perri, and Violante (2010) for 1967). We choose  $\phi$  so that the aggregate labor supply in steady state equals 1/3 (as is commonly assumed in the macro literature). We calibrate  $\beta$  so that the capital-to-output ratio equals 2.9 (approximately the average of 1970 – 2011 as reported in the NIPA and Fixed Asset Tables data). Finally, following Heathcote, Storesletten, and Violante (2014), we choose  $\lambda$  to clear the government budget constraint in equilibrium. Table 2 summarizes our calibration procedure.

### 3.1 Model Fit

This subsection briefly discusses how well the calibrated model fits 1967 U.S. economy. Even though the model calibration only targets the skill premium for 1967, the model is successful in terms of matching wage and earnings Gini coefficients and variance of logs. The Gini coefficient for wages in the data is 0.28 whereas the model generates 0.26. Similarly, the Gini for earnings is 0.35 while the model delivers 0.37. The model produces a similarly good fits if we use the variance of logged wages and earnings. These results are contained in Table 3 below.

## 4 Changes in Inequality Between 1960's and 2000's

In recent decades, the U.S. economy has faced (i) a decline in the price of equipments, (ii) an increase in the relative supply of skilled workers, (iii) an increase in residual wage volatility, (iv) an increase in the progressivity of the labor income taxes, (v) a decrease in capital taxation. In this section, we evaluate the effects of these changes on the evolution of wage and earnings inequality in the United States. Specifically, we compute the SRCE of the model economy under the 2000s technology, skill supply, residual wage risk, and tax parameters. Our aim is (i) first, to understand how much of the changes in wage and earnings inequality that we observe in the data our model can explain, and (ii) second, to assess how different factors contribute to changes in inequality.

Before we discuss these findings in more detail, in Section 4.1 below, we describe in more detail the changes in factors that affected wage and earnings inequality during the period 1960's and 2000's, which we consider in our analysis.

### 4.1 Changes in Factors

This section documents the changes in technology, relative supply of skilled workers, residual wage volatility, and labor income taxes between the 1960's and the 2000's.

**Technology.** Our measure of technology is the price of equipment capital,  $q$ . Cummins and Violante (2002) document that the price of equipment capital decreases from the normalized value 1 in 1967 to 0.2011 in 2000. This means that if 1 unit of consumption good is needed to produce 1 unit of equipments in 1967, 0.2011 units of consumption good is needed in year 2000. Since different types of labor have different elasticity of substitution with equipment capital, the change in the price of equipment capital endogeneously implies a change in the skill premium, i.e., skill-biased technical change. Following Krusell, Ohanian, Ríos-Rull, and Violante (2000), we assume that price of structure capital relative to consumption good remains constant over time.



**Supply of skilled workers.** We compute the fraction of skilled to unskilled workers,  $p_s/p_u$ , for year 2000 using CPS data in a way identical to the value we computed for 1967. We find that relative skilled supply increased from 0.1356 in 1967 to 0.2865 in 2000.

**Redisual wage risk.** The persistence of the productivity process,  $\rho$ , changes from 0.8253 to 0.8137 and the variance of the innovations,  $var(\epsilon)$ , change from 0.0653 to 0.1530. We recover these from the calculations provided by Heathcote, Storesletten, and Violante (2010). The details of the parameter specifications for both 1967 and 2000 are given in Appendix A.

**Progressivity of the labor taxes.** The tax labor progressivity parameter,  $\tau_l$ , changes from 0.08 to 0.17 as reported in Bakis, Kaymak, and Poschke (2014).

**Capital taxation.** Gravelle (2011) documents that the effective tax rates on structures and equipments at the corporate level were 32% and 26% in the 2000's. Combining these with the 15% capital income tax rate at the consumer level implies an overall tax on structure capital of  $\tau_s = 1 - 0.85 \cdot (1 - 0.32) = 42.2\%$  and an overall tax on equipment capital of  $\tau_e = 1 - 0.85 \cdot (1 - 0.26) = 37.1\%$  in the 2000's while in the 1960's the numbers were substantially larger, namely 56.7% and 49.9%.

We solve for the steady state using these new parameters and keep the rest of the parameters of the model unchanged. The only exception is the labor tax constant  $\lambda$ , which is set so that the government budget clears in the new steady state.

## 4.2 Change in Inequality

This section evaluates the model's success in explaining the observed changes in wage and earnings inequality in the United States between 1960s and 2000s. Table 3 summarizes the main findings. All the data values in Table 3 are taken from Heathcote, Storesletten, and Violante (2010). First, we want to see how well the model matches the level of inequality in

Table 3: Change in Inequality

	Data			Model		
	1967	2000s	Change	1967	2000s	Change
Skill premium	1.55	1.8	16%	1.55	1.88	21%
Varlog of Wages	0.25	0.45	80%	0.23	0.53	135%
Wage Gini	0.28	0.37	32%	0.26	0.38	50%
Varlog of Earnings	0.5	0.75	50%	0.49	1.02	107%
Earnings Gini	0.35	0.42	20%	0.37	0.51	36%

This table compares the actual and model generated levels of and changes in wage and earnings inequality between 1960's and 2000's. All the data in this table are from Heathcote, Perri, and Violante (2010)

1967. To do so, compare first and fourth columns of Table 3. The first row shows that we perfectly match skill premium but this is no success since skill premium is a target in the calibration. A comparison of the second and third rows shows that the model does quite well in matching observed wage inequality in 1967. The fourth and fifth rows show that the model is doing well also in matching observed earnings inequality.

Second, we discuss how well the model does in matching the change in inequality during the period of interest. Comparing the third and the sixth columns of Table 3, first we see that the model does a very good job in replicating the rise in skill premium: 16% in the data vs. 19% in the model. Regarding all the other inequality measures, the model gives a somewhat larger rise in inequality.

### 4.3 Decomposing the Change in Inequality

In this section, we decompose the total change in inequality between the 1960's and the 2000's that the model generates into changes that are coming from i) skill-biased technical change (coming from the change in the price of equipment capital), ii) the change in the relative supply of skilled people, iii) the change in residual wage risk, and iv) changes in the tax code. To do so, we compute a steady state equilibrium of an economy where we feed in the observed change in one of these parameters but keep the rest of them fixed at their 1967 level. This allows us to see the contribution of each factor to the overall change in inequality.

Table 4: Decomposing Changes in Inequality

	$q$	$p_s/p_u$	risk	$\tau_k$	$\tau_l$	Total
Skill premium	129%	-56%	8%	3%	-2%	19%
Varlog of Wages	73%	4%	113%	1%	-1%	135%
Wage Gini	43%	2%	42%	1%	0%	50%
Varlog of Earnings	31%	6%	115%	2%	-9%	107%
Earnings Gini	20%	2%	36%	1%	-4%	36%

This table decomposes the changes in skill premium and overall wage and earnings inequality to changes coming from price of technology, relative supply of skilled workers, residual wage risk, changes in capital taxation and changes in labor tax progressivity.

Table 4 summarizes decomposition results (Table 5 provides the same results in levels). The last column gives the total change in model inequality between 1960's and 2000's whereas the first to fifth fourth columns report the change in inequality that would have occurred if only the price of technology, relative skill supply, residual wage risk, capital taxes, or labor tax progressivity would have changed as observed in the data.

The first row of Table 4 decomposes the change in the skill premium. We see that if the decline in the price of equipments was not offset by an increase in relative supply of skilled agents, then skill premium would have increased much more. Intuitively, when the price of equipment capital decreases, more equipment capital is accumulated in the new steady state. This increases the demand for skilled agents endogenously. The increase in the supply of skilled agents meets the increased demand, but only to a certain degree, explaining the total rise in the skill premium. This is the famous race between technology and education.<sup>5</sup>

Interestingly, as the first row of the third column in Table 4 shows, the increase in residual wage risk also adds substantially to the rise of the skill premium. The mean of the productivity processes are normalized to one both in 1960's and 2000's distributions, and thus, holding skilled and unskilled wages fixed, the skill premium is independent of the distribution of productivity shocks. However, the change in residual wage risk affects the skill premium through a novel mechanism that has not been previously analyzed in the literature.

<sup>5</sup>See Goldin and Katz (2008). The race terminology is originally due to Tinbergen (1974).

Table 5: Decomposing Changes in Inequality in Levels

	1960's	2000's	$q$	$p_s/p_u$	risk	$\tau_l$	$\tau_k$
Skill premium	1.550	1.875	3.556	0.677	1.669	1.518	1.589
Varlog of Wages	0.227	0.534	0.393	0.236	0.484	0.225	0.230
Wage Gini	0.256	0.385	0.368	0.260	0.364	0.256	0.258
Varlog of Earnings	0.490	1.015	0.644	0.518	1.056	0.446	0.501
Earnings Gini	0.374	0.510	0.450	0.382	0.511	0.359	0.378

This table decomposes the changes in skill premium and overall wage and earnings inequality to changes coming from price of technology, relative supply of skilled workers, residual wage risk, changes in labor tax progressivity and changes in capital taxation.

An increase in residual wage risk leads to higher precautionary savings and thus to higher levels of aggregate capital. Due to capital-skill complementarities in the production function, this leads to an increase in the skill premium and thus to a further increase in inequality. Finally, we see that capital taxation and the progressivity of the labor tax code does not affect the skill premium significantly as they do not effect other variables. This is mainly due to the fact that there is no human capital accumulation in the current model.<sup>6</sup>

The second to fifth rows of Table 4 summarize how the four factors contribute to overall wage and earnings inequality. The first column shows that the decline in the price of technology has increased wage and earnings inequality, as measured by either Gini coefficients or variance of logarithms. The decline in technology price affects wage and earnings inequality via its effect on skill premium. Importantly though, the way a higher skill premium affects wage and earnings inequality is not trivial. On the one hand, changes in wages mean that each skill group will have more or less dispersed wage and earnings distributions. On the other hand, depending on how the skilled and unskilled distributions stood relative to each other in 1967, a higher skill premium might increase or decrease the overlap between the two distributions. We see that at the end higher technology increases wage and earnings inequality. A comparison of the first and third rows show that, regarding wage inequal-

<sup>6</sup>For an analysis of how labor taxes affect skill premium in a model with human capital accumulation, see Guvenen, Kuruscu, and Ozkan (2014).

ity, the contribution of skill-biased technical change is, in fact, of similar magnitude as the contribution of the change in residual wage risk.

The increase in the supply of skilled agents have one direct and one indirect effect on the dispersion of wage and earnings. The direct effect is that as the ratio of skilled and unskilled changes, the number of people in each wage or earnings bin changes even if there was no change in wage or earning levels. The indirect effect - like the effect of change in the price of equipments - works through the skill premium. Higher supply of skilled people in the 2000's depresses the skill premium. This first of all compresses wage and earnings distributions for each skill group, implying a decline in overall wage and earnings inequality. Again, depending on the initial position of the two distributions, a decline in the skill premium can increase or decrease the overlap between the two distributions. We see that these different forces almost cancel each other out and, at the end, the increase in the supply of skilled workers does not have much effect on wage and earnings inequality.

The next column in the table shows that higher residual wage dispersion contributes the most to higher wage and earnings inequality. This is an obvious mechanical effect. We see that capital taxation and labor tax progressivity do not affect wage inequality almost at all. This is due to the fact that there is no skill choice in the model and hence tax progressivity does not affect the skill premium through skill choice. The change in tax progressivity has a modest decreasing effect on earnings inequality, mainly because with higher progressivity of the tax code in 2000's, skilled agents work less and earn less.

#### **4.4 Other Factors**

Of course, there are other factors that have affected the evolution of inequality in the United States during 1967-2000 such as labor market institutions (unionization, minimum wages), immigration, offshoring etc. It would be interesting to include some of these factors to the model set up in this paper.

## 5 Conclusion

This provides two sets of findings. First, it finds that the observed changes in inequality can be quite well explained by a model that incorporates the technology-education race model of Tinbergen (1974) into a standard incomplete markets model that macroeconomists use to study inequality (in fact the model predicts a larger increase in inequality than in the data). Second, the paper decomposes the changes in the skill premium and in overall inequality into four components: skill-biased technical change, increase in the relative supply of skilled workers, increase in residual wage volatility, and changes in tax policy. In line with Tinbergen (1974)'s technology-education race theory, this paper finds that the skill premium is most significantly affected by the changes in technology and supply of skilled workers. In addition, this paper also identifies a mechanism not previously analyzed in the literature: an increase in residual wage risk leads to higher precautionary savings and thus to higher levels of aggregate capital. Due to capital-skill complementarities in the production function, this leads to an increase in the skill premium and thus to a further increase in inequality.

The next steps in this project are the following. First, we are currently working on estimating empirical tax functions for the period 1960's - 2010's using the PSID data and the TAXSIM program. Second, we are working on incorporating the actual technology-education race model into the simplified environment.

## References

- AUERBACH, A. J. (1983): “Corporate Taxation in the United States,” *Brookings Papers on Economic Activity*, 14(2), 451–514.
- AUTOR, D. H., L. F. KATZ, AND M. S. KEARNEY (2006): “The Polarization of the U.S. Labor Market,” *American Economic Review*, 96(2), 189–194.
- BAKIS, O., B. KAYMAK, AND M. POSCHKE (2014): “On the Optimality of Progressive Income Redistribution,” Working paper.
- BUERA, F. J., J. P. KABOSKI, AND R. ROGERSON (2015): “Skill-Biased Structural Change and the Skill-Premium,” Discussion paper.
- CUMMINS, J. G., AND G. L. VIOLANTE (2002): “Investment-Specific Technical Change in the US (1947-2000): Measurement and Macroeconomic Consequences,” *Review of Economic Dynamics*, 5(2), 243–284.
- GOLDIN, C., AND L. F. KATZ (2008): *The Race between Education and Technology*. Cambridge, MA: Harvard University Press.
- GRAVELLE, J. G. (2011): “Reducing Depreciation Allowances to Finance a Lower Corporate Tax Rate,” *National Tax Journal*, 64(4), 1039–1054.
- GREENWOOD, J., Z. HERCOWITZ, AND P. KRUSELL (1997): “Long-Run Implications of Investment-Specific Technological Change,” *American Economic Review*, 87(3), 342–362.
- GUVENEN, F., AND B. KURUSCU (2010): “A Quantitative Analysis of the Evolution of the U.S. Wage Distribution, 1970-2000,” in *NBER Macroeconomics Annual 2009, Volume 24*, NBER Chapters, pp. 227–276. National Bureau of Economic Research, Inc.
- (2012): “Understanding the Evolution of the US Wage Distribution: A Theoretical Analysis,” *Journal of the European Economic Association*, 10(3), 482–517.

- GUVENEN, F., B. KURUSCU, AND S. OZKAN (2014): “Taxation of Human Capital and Wage Inequality: A Cross-Country Analysis,” *Review of Economic Studies*, 81, 818–850.
- HE, H. (2012): “What drives the skill premium: Technological change or demographic variation?,” *European Economic Review*, 56(8), 1546–1572.
- HE, H., AND Z. LIU (2008): “Investment-Specific Technological Change, Skill Accumulation, and Wage Inequality,” *Review of Economic Dynamics*, 11(2), 314–334.
- HEATHCOTE, J., F. PERRI, AND G. L. VIOLANTE (2010): “Unequal We Stand: An Empirical Analysis of Economic Inequality in the United States: 1967–2006,” *Review of Economic Dynamics*, 13(1), 15–51.
- HEATHCOTE, J., K. STORESLETTEN, AND G. L. VIOLANTE (2010): “The Macroeconomic Implications of Rising Wage Inequality in the United States,” *Journal of Political Economy*, 118(4), 681–722.
- (2014): “Consumption and Labor Supply with Partial Insurance: An Analytical Framework,” *American Economic Review*, 104(7), 2075–2126.
- HECKMAN, J., L. LOCHNER, AND C. TABER (1998): “Explaining Rising Wage Inequality: Explorations With A Dynamic General Equilibrium Model of Labor Earnings With Heterogeneous Agents,” *Review of Economic Dynamics*, 1(1), 1–58.
- KOPECKY, K., AND R. SUEN (2010): “Finite State Markov-chain Approximations to Highly Persistent Processes,” *Review of Economic Dynamics*, 13(3), 701–714.
- KRUEGER, D., AND A. LUDWIG (2013): “Optimal Progressive Taxation and Education Subsidies in a Model of Endogenous Human Capital Formation,” Working paper.
- KRUSELL, P., L. E. OHANIAN, J.-V. RÍOS-RULL, AND G. L. VIOLANTE (2000): “Capital-Skill Complementarity and Inequality: A Macroeconomic Analysis,” *Econometrica*, 68(5), 1029–1054.



MENDOZA, E. G., A. RAZIN, AND L. L. TESAR (1994): “Effective tax rates in macroeconomics: Cross-country estimates of tax rates on factor incomes and consumption,” *Journal of Monetary Economics*, 34(3), 297–323.

SLAVÍK, C., AND H. YAZICI (2015): “On the Consequences of Eliminating Capital Tax Differentials,” Working paper.

TINBERGEN, J. (1974): “Substitution of Graduate by Other Labour,” *Kyklos*, 27(2), 217–26.

# Appendix

## A Productivity Process

Using PSID data from 1967 - 2000, Heathcote, Storesletten, and Violante (2010) estimate the following wage process with a transitory shock  $\nu$  and a persistent shock  $\omega$ :

$$y_t = \eta_t + \nu_t, \tag{2}$$

$$\eta_t = \rho_\eta \eta_{t-1} + \omega_t. \tag{3}$$

For computational tractability, we use a wage process with a single shock:

$$\bar{y}_t = \rho_{\bar{y}} \bar{y}_{t-1} + u_t.$$

We set  $\rho_{\bar{y}}$  and  $var(u_t)$  so that the wage process  $\bar{y}_t$  has the same persistence and variance as the wage process  $y_t$  estimated by Heathcote, Storesletten, and Violante (2010).

Specifically, if the wage process defined in equations (2) and (3) is time invariant, one

gets the following relationships (assuming the distribution of  $\eta_t$  is stationary):

$$\begin{aligned} \text{var}(y) &= \frac{\text{var}(\omega)}{1 - \rho_\eta^2} + \text{var}(\nu), \\ \rho_y &= \frac{\frac{\text{var}(\omega)}{1 - \rho_\eta^2}}{\frac{\text{var}(\omega)}{1 - \rho_\eta^2} + \text{var}(\nu)}. \end{aligned}$$

To match these properties, we set:

$$\begin{aligned} \rho_{\bar{y}} &= \rho_y, \\ \text{var}(u) &= \text{var}(y)(1 - \rho_y^2). \end{aligned}$$

Heathcote, Storesletten, and Violante (2010) estimate a single  $\rho_\eta$  and a time series for the standard deviations of the shocks  $\sigma_t^\omega$  and  $\sigma_t^\nu$ . To approximate the standard deviations of the shocks for our simulations of the initial year 1967, we take the average of the standard deviations reported in Heathcote, Storesletten, and Violante (2010) for 1967 - 1971. Similarly, for our simulations of 2000's, we take the average of the standard deviations reported in Heathcote, Storesletten, and Violante (2010) for 1996 - 2000.<sup>7</sup> We use these means to recover  $\rho_{\bar{y}}$  and  $\text{var}(u)$  for 1967 and 2000 using the relationships above.

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<sup>7</sup>Using linear regressions in time to abstract from temporary changes in the standard deviations generates very similar statistics.