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

Ctirad Slavík and Hakki Yazici[*]

July 28, 2015

The skill premium in the United States has gone up significantly between the 1960's and the 2000's. During the same period, individual wage volatility has also increased. Using a model that incorporates the technology-education race model of Tinbergen (1974) into a standard incomplete markets model, this paper shows that the rise in individual wage risk is an important contributor to the rise in skill premium. Depending on the decomposition method, the rise in wage risk explains 9% or 17% of the total rise in skill premium between the 1960's and the 2000's.

*JEL classification:* E25, J31.

*Keywords:* Skill premium, wage risk, precautionary savings, capital-skill complementarity.

# 1 Introduction

The skill premium, which is defined as the ratio of the average wage of college educated people to the average wage of those without college education has gone up from 1.52 in the late 1960's to 1.87 in the early 2000's. Two factors that have found significant support in the literature in terms of determining the changes in skill premium are technological advancements that favor skilled workers (skill-biased technical change) and the rise in the relative supply of skilled workers.[1] The notion that relative wages of college vs. non-college graduates are determined as a result of the 'race' between technology and education is originally due to Tinbergen (1974). Intuitively, skill-biased technical change has increased the demand for skilled workers, thereby putting an upward pressure on skill premium. This pressure has been offset to a certain degree by the increase in the relative number of college graduates. Overall, however, the skill-biased technical change has been dominant, resulting in skill premium to increase.

Another important finding that has been documented by Gottschalk and Moffitt (1994) and Heathcote, Storesletten, and Violante (2010), among others, is that U.S. workers face a considerably higher level of individual wage risk now than they used to in the past.[2] In this paper, we show that the rise in individual wage risk is a quantitatively significant contributor to the rise in skill premium. We do so by constructing a model that incorporates the technology-education race model of Tinbergen (1974) into a standard incomplete markets model that macroeconomists use to study inequality.

---

[1]See Tinbergen (1974), Krusell, Ohanian, Ríos-Rull, and Violante (2000), and Goldin and Katz (2008), among many others. See also Acemoglu and Autor (2011) for a survey of the literature.

[2]In contrast, Sabelhaus and Song (2010) and Guvenen, Kuruscu, and Ozkan (2014) argue against this finding.

We first test our model by studying whether it can explain the rise in the skill premium observed between the 1960's and the 2000's once we feed in the observed changes in (i) traditional channels (skill-biased technical change and the rise of the relative supply of skilled workers), (ii) individual wage risk, (iii) government policy during the same period. Then, we use the model to decompose the changes in the skill premium into components that are coming from (i)-(iii). Our most important finding is that the rise in uninsurable wage risk has been a quantitatively significant factor in the rise of the skill premium.

Specifically, we build 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 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 U.S. economy. Then, we feed in the 2000's observed values of the equipment prices, the relative supply of skilled labor, individual wage risk, and government policy. 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.

We find that the model overestimates somewhat the increase in the skill premium. Skill premium in the data increases by 35 percentage points, from 1.52 in the 1960's to 1.87 in the 2000's whereas in the model it increases by 38 percentage points, from 1.52 to 1.90. Regarding the decomposition of the change in skill premium, in line with the technology-race model, we find that the traditional channels (skill-biased technical change and the rise in the relative supply of skilled workers) explain a substantial part of the change in the skill premium from the 1960's to the 2000's. We propose two different ways of measuring the contribution of each channel, and, in our benchmark specification, the traditional channels explain 76% or 84% of the total change in the skill premium depending on the specific measurement strategy.

The increase in wage risk also explains a significant fraction of the change in skill premium: depending on the measurement strategy, it accounts for 17% or 9% of the total rise in skill premium. To the best of our knowledge, the idea that the rise in individual wage risk can increase the skill premium 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 changes in capital taxes and debt policy contribute the least to the rise of the skill premium.

In the baseline model, we treat the United States as a closed economy. In Section 5, we illustrate to what extent our results depend on the closed economy assumption. First, we investigate whether our model's success in replicating the observed change in the skill premium survives if we instead model the United States as an

4

open economy. We find that whether one models the United States as a closed or as a small open economy does not change the model's prediction regarding the overall rise in the skill premium. Second, we analyze whether the rise in individual wage risk, which contributes to the rise of the skill premium in the closed economy model, is still a quantitatively significant factor in causing the skill premium to rise if one assumes that the U.S. is a small open economy. We conclude that the small open economy assumption is not a good assumption to analyze this issue: one needs to model how aggregate savings of the U.S. economy affect the world interest rate in order to analyze the effect of changes in wage risk on skill premium.[3]

**Related Literature.** This paper is related to three different strands of literature. First, it relates to a growing literature that aims to explain the evolution of the 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 the skill premium between 1965 and 1992. Buera, Kaboski, and Rogerson (2015) analyzes the role of structural change on the change of the skill premium between 1977 and 2005. He and Liu (2008) aims to match the evolution of the skill premium between 1949 and 2000 using a model that features skill-biased technical change along with endogenous skill supply. They model skill-biased technical change using the production function estimated by Krusell, Ohanian, Ríos-Rull, and Violante (2000) and the decline in equipment capital prices. He (2012) studies the effects of skill-biased technical change in a model with demographic change. We add to this literature by uncovering a novel factor

---

[3]We are currently working on a large open economy version of the model.

that has contributed to the observed rise in the skill premium, namely the increase in wage risk. In particular, we show that this factor is quantitatively important.

By modelling wage risk in an incomplete markets environment, this paper is related to a large literature in the Bewley (1986), Imrohoroglu (1989), Huggett (1993), Aiyagari (1994) tradition. The paper that is most closely related to our paper in this literature is Heathcote, Storesletten, and Violante (2010). This paper estimates the changes in labor income risk over time (and we make use of their estimates) and then analyzes the macroeconomic implications of this change along with the changes in skill premium and gender gap. Unlike the current paper, Heathcote, Storesletten, and Violante (2010) do not aim to explain the reasons behind the changes in the skill premium.

More broadly, our paper is 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.

The rest of the paper is structured as follows. Section 2 describes the model in

detail while Section 3 lays out our calibration strategy. Section 4 discusses our main findings. Section 5 considers the open economy extension. Section 6 concludes.

## 2   Model

We develop an infinite horizon closed economy growth model with two types of capital (structures and equipments), two types of labor (skilled and unskilled), consumers, a firm, and a government. We consider an open economy version of this model in Section 5.

**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. 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 model the increase in relative supply of skilled workers by letting $\pi_s$ to increase from its value in 1960's to that in 2000's.

In addition to heterogeneity between skill groups, there is heterogeneity within each skill group because agents face idiosyncratic labor productivity shocks over time. The productivity shock, denoted by $z$, follows a Markov chain with states $Z = \{z_1, ..., z_I\}$ and transitions $\Pi(z'|z)$. We parameterize the skill process in Sec-

tion 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

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

where $\beta$ is the time discount factor. The functions $u$ and $v$ satisfy $u', -u'', v', v'' > 0$. The unconditional expectation, $E$ is taken with respect to the stochastic processes governing the idiosyncratic labor shock. There are no aggregate shocks. Modelling elastic labor supply is especially important in our model since this gives agents an additional tool to insure income shocks. In this sense, excluding labor supply responses of the agents could make agents to do more precautionary savings and overstate the importance of our mechanism.

**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).

Since the two types of labor are not perfect substitutes, the production function we use also implies that an increase in skilled labor supply, which makes skilled labor less scarce, leads to a decrease in the skill premium. An increase in unskilled labor supply has the opposite effect.

Finally, we assume that 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 that 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 model skill-biased technical change by a drop in $q$ from its 1960's level to 2000's level.

**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 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 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., $R = 1 + (r_s - \delta_s)(1 - \tau_s) = \frac{q + (r_e - q\delta_e)(1 - \tau_e)}{q}$, 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 $i \in \{u, s\}$:

$$V_i(z,a) = \max_{(c_i, l_i, a'_i) \geq 0} \quad u(c_i) - v(l_i) + \beta \sum_{z'} \Pi_i(z'|z) V_i(z', a'_i) \quad \text{s.t.}$$
$$(1 + \tau_c)c_i + a'_i \leq w_i z l_i - T(w_i z l_i) + Ra,$$

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

2. The firm solves:

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

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 the 1960's technology, relative supply of skilled workers, residual wage risk, and taxes coincides with 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 the 1960's along selected dimensions. The internal calibration procedure is summarized in Table 2. The term 1960's refers to the period 1967-1971. 1967 is chosen as the starting year because

the earliest available estimates for individual labor income risk, coming from the Panel Study of Income Dynamics (PSID), are from 1967. We consider the five year period 1967-1971 because we think of our starting point as a steady state and we want to abstract from the peculiarities of any particular calendar year.

Because of data availability reasons, we focus on working age males, when comparing model with data. This concerns the skill premium, educational attainment as well the idiosyncratic productivity process.

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 and are consistent with balanced growth. 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):

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

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 report their

estimates of $\omega$ and $\rho$. We calibrate these parameters internally to U.S. data, as we explain in detail below. We also normalize the price of equipment capital $q = 1$ for the benchmark 1960's 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 Heathcote, Storesletten, and Violante (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 for the period 1978-2006, Heathcote, Storesletten, and Violante (2014) estimate $\tau_l = 0.185$. We assume that this parameter has not changed between the 1960's and the 2000's. We use their estimate and calibrate $\lambda$ to clear the government budget. We believe that modelling the progressivity of the US tax system is important for measuring the importance of changes in risk. This is because progressive tax systems provide partial insurance against labor income risk. This way a higher degree of progressivity can decrease the risk agents face and thereby decrease the need for precautionary savings.

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 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

14

## Table 1: Benchmark Parameters for the 1960's

| 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 |
| Fraction of skilled workers in the 1960's | $\pi_s^{60}$ | 0.1444 | CPS |
| **Productivity** | | | |
| Persistence of the autoregresive component | $\xi$ | 0.9733 | HSV |
| Variance of the transitory shock in the 1960's | $\sigma_\varepsilon^{60}$ | 0.0314 | HSV |
| Variance of the persistent shock in the 1960's | $\sigma_\kappa^{60}$ | 0.0093 | HSV |
| **Government polices** | | | |
| Labor tax progressivity in the 1960's | $\tau_l$ | 0.185 | HSV (2014) |
| 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 | $D/Y$ | 0.36 | St. Louis FED |

This table reports the benchmark parameters that we take directly from the literature or the data. The acronyms BKP, GHK, HSV, HSV (2014), KORV, KL, and MTR stand for Bakis, Kaymak, and Poschke (2014), Greenwood, Hercowitz, and Krusell (1997), Heathcote, Storesletten, and Violante (2010), 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.

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 36% of GDP, which is the average for the 1967 - 1971 period, as reported by the Federal Reserve Bank of St. Louis Database.

The fraction of skilled agents, $\pi_s^{60}$, is calculated to be 0.1444 using the Current Population Survey (CPS) for the 1960's. This is the average of the five year period from 1967 to 1971. We consider educational attainment for males 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 the idiosyncratic productivity shocks $z$ 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 $E[z] = 1$ in both 1960's and the 2000's.[4] We model the log of the idiosyncratic stochastic component of the wage rate as the sum of two orthogonal components: a persistent autoregressive shock and a transitory shock.

---

[4]A change in the mean of $z$ over time would be similar to an exogenous labor augmenting technical change. In our environment, such technical change would not be neutral: a change in the mean of $z$ would lead to change in aggregate capital and hence to changes in the skill premium. Since we focus on how the changes in risk associated with $z$ affects skill premium, we want to abstract from changes in skill premium implied by changes in mean $z$.

More precisely,

$$\log z_t = \theta_t + \varepsilon_t,$$

$$\theta_t = \xi\theta_{t-1} + \kappa_t,$$

where $\varepsilon_t$ and $\kappa_t$ are drawn from distributions with mean zero and variances $\sigma_\varepsilon^d$ and $\sigma_\kappa^d$, where $d$ refers to the decade. Heathcote, Storesletten, and Violante (2010) estimates the labor income risk process expressed above (for males aged 25-60 with at least 260 working hours per year) for every year between 1967 and 2000 assuming that the persistence parameter $\xi$ is time-invariant. We set $\xi = 0.9733$ which is their estimate. We set $\sigma_\varepsilon^{60} = 0.0314$ and $\sigma_\kappa^{60} = 0.0093$, which are both the averages of the relevant variances over the 1967-1971 period as estimated by Heathcote, Storesletten, and Violante (2010). We approximate these processes by finite number Markov chains using the Rouwenhorst method described in Kopecky and Suen (2010). In Section 4, we model the change in idiosyncratic wage risk by changing parameters of the wage process from their value in 1960's to those in 2000's.

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 1.52 (as reported by Heathcote, Perri, and Violante (2010) for the late 1960's which again is calculated as the average of the five year period from 1967 to 1971, for males aged 25-60 with at least 260 working hours per year). We choose $\phi$ so that the aggregate labor supply in steady state equals 1/3 (as

Table 2: Benchmark Calibration Procedure for the 1960's

| Parameter | Symbol | Value | Target | Data & SRCE | Source |
|---|---|---|---|---|---|
| Production parameter | $\omega$ | 0.8181 | Labor share | 2/3 | NIPA |
| Production parameter | $\nu$ | 0.4242 | Skill premium in 60's | 52% | HPV |
| Disutility of labor | $\phi$ | 6.6868 | Labor supply | 1/3 | |
| Discount factor | $\beta$ | 0.9848 | Capital-to-output ratio | 2.9 | NIPA, FAT |
| Tax function parameter | $\lambda$ | 0.8747 | 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.

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.

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

Between 1960's and 2000's, the U.S. economy has faced (i) a decline in the price of equipments (skill-biased technical change), (ii) an increase in the relative supply of skilled workers, (iii) an increase in residual wage risk, (iv) a decline in capital taxes and an increase in government debt. In this section, we evaluate the effects of these changes on the skill premium using our model. The skill-biased technical change and the change in relative supply of skilled workers have long been seen as two main determinants of the evolution of skill premium.[5] Therefore, we refer

---

[5]See Krusell, Ohanian, Ríos-Rull, and Violante (2000), among many others.

to the cumulative effect of these two factors as the change in skill premium that is coming from the 'traditional channels.' Our aim is (i) to understand how much of the changes in skill premium that we observe in the data our model can explain, and (ii) to assess how changes in different factors - traditional channels, policy, and risk - have contributed to the change in skill premium.

Before we discuss these findings, in Section 4.1 below, we first describe in detail the changes in traditional channels, policy and risk that have occured between the 1960's and the 2000's.

## 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 technological improvement (skill-biased technical change) is the changes in the price of equipment capital, $q$. Cummins and Violante (2002) document that the price of equipment capital decreased from the normalized value of 1 in 1967 to 0.2011 in 2000. This means that if 1 unit of the general consumption good was needed to produce 1 unit of equipments in 1967, 0.2011 units of the general consumption good was needed in year 2000. For the price of equipment capital in 1960's, we take the average of $q$ over the five year period 1967-1971, which is equal to 0.9328. Since Cummins and Violante (2002) does not report $q$ after 2000, we interpolate it for the period 2001-2005 by using the average growth rate of $q$ during the period 1967-2000. We compute average $q$ for the period 2001-2005 to be 0.1744, and call that the price of equipment capital in the 2000's. We normalize the price of equipments in the 1960's to 1, which implies the price of

equipments in the 2000's is equal to 0.1744/0.9328=0.187.

Since different types of labor have different elasticity of substitution with equipment capital, the decline in the relative price of equipment capital endogenously implies a change in the skill premium, i.e., skill-biased technical change. In the data provided by Cummins and Violante (2002), the price of structure capital relative to consumption good remains virtually constant during this period. For this reason, we keep the price of structures at its normalized 1960's price of 1.

**Supply of skilled workers.** We compute the fraction of skilled workers for years 2001 to 2005 following the same procedure we used to compute it for 1960's. The average fraction for 2000's, $\pi_s^{00}$, is given by taking the average of this value for the five year period between 2001 and 2005. We find that the fraction of skilled workers increased from 0.1444 in 1960's to 0.2952 in 2000's. Again, we only consider males who are 25 years and older and who have earnings.

**Residual wage risk.** The persistence of the productivity process, $\xi$, is assumed to be time invariant following Heathcote, Storesletten, and Violante (2010). The variances of the transitory and persistent shocks for the 2000's is computed by taking the average over the period 1996-2000.[6] The variance of the innovations to the autoregressive component increases from $\sigma_\kappa^{60} = 0.0093$ to $\sigma_\kappa^{00} = 0.0200$. The variance of the transitory shock goes up from $\sigma_\varepsilon^{60} = 0.0314$ to $\sigma_\varepsilon^{00} = 0.0746$. We recover these from Heathcote, Storesletten, and Violante (2010).

**Capital taxes and government debt.** Gravelle (2011) documents that the effective tax rates on structures and equipments at the corporate level were 32% and

---

[6]Since 2000's refer to the period 2001-2005 throughout the paper, ideally we would like to take averages of the variances for this period as well. We use 1996-2000 data for now because these are the latest estimates available from Heathcote, Storesletten, and Violante (2010).

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%. Using the St. Louis Fed macroeconomic database, we compute that the U.S. government debt increases from 0.36 during 1967-1971 period to 0.58 during the 2001-2005 period.

We keep government consumption as a fraction of GDP constant between the steady states that represent the 1960's and the 2000's, because it is fairly constant in the data. We also fix the labor tax progressivity between the 1960's steady state and the 2000's steady state. The reason is that existing estimates of progressivity rely on the TAXSIM program, which does not include state taxes prior to 1978 and, hence, labor tax progressivity for 1960's cannot be properly measured.[7] Finally, we also keep consumption taxes fixed.

We solve for the steady state using the 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 Skill Premium

This section evaluates the model's success in explaining the observed changes in the skill premium in the United States between the 1960's and the 2000's. Table 3 summarizes the main findings. Following Heathcote, Perri, and Violante (2010),

---

[7]Kaymak and Poschke (2015) try to overcome the issue and estimate that $\tau_l = 0.08$ in the 1960's and $\tau_l = 0.17$ in the 2000's. We also performed an exercise in which we changed the labor tax progressivity using their estimates, but we found that changes in labor tax progressivity do not have a big impact on neither the skill premium nor on how important changes in labor income risk are. We do not report these results in the paper.

Table 3: Change in Inequality

| | Data | | | Model | | |
|---|---|---|---|---|---|---|
| | 1960's | 2000's | Change | 1960's | 2000's | Change |
| Skill premium | 1.52 | 1.87 | 0.35 | 1.52 | 1.90 | 0.38 |

This table compares the actual and model generated levels of and changes in skill premium between 1960's and 2000's. The skill premium data in this table are computed using CPS data for males between ages of 25 to 60 who work at least 260 hours a year. The skill premium in 1960's (2000's) refer to the average of skill premium over the period 1967-1971 (2001-2005).

the value of skill premium for 1960's and 2000's are computed using CPS data focusing on males between ages of 25 and 60, working at least 260 hours a year. As with other variables, the skill premium for 1960's (2000's) is computed taking average over the five year period 1967-1971 (2001-2005).

Looking at Table 3, we first notice that the model generates the exact value of skill premium in 1960's. This is so because the 1960's skill premium is a calibration target. Comparing the second and the fifth columns of the table, we observe that the model does a good job in replicating the level of skill premium in 2000's: it overshoots the level of skill premium in 2000's by only three percentage points. Restated in terms of changes, the model does a very good job in replicating the rise in skill premium: 35 percentage points in the data vs. 38 percentage points in the model.

## 4.3 Decomposing the Change in the Skill Premium

In this section, we decompose the total change in the skill premium between the 1960's and the 2000's that the model generates into changes that are coming from i) the traditional channels (skill-biased technical change, i.e., the change in the price of equipments, and the change in the relative supply of skilled people), ii) the

change in residual wage risk, and iii) changes in tax and debt policies. We perform this decomposition in two alternative ways.

First, we compute a steady-state equilibrium of an economy where we feed in the observed changes in traditional channels but keep risk and policy at their 1960's levels. A comparison of the skill premium of this economy with the 1960's skill premium reveals how much of the total change in skill premium can be explained by the changes in traditional channels. Then, we solve for a steady state equilibrium in an economy in which government policy as well as the traditional channels have changed. A comparison of the skill premium of this economy with the skill premium of the economy with changes in traditional channels only tells us what the contribution of the changes in policy to the rise in skill premium is. Finally, we compute the steady-state equilibrium of the economy in which all four factors including risk has changed to its 2000's levels. A comparison of the skill premium in the latter economy with the skill premium in the economy where all factors but risk has changed gives us the contribution of the rise in risk to the rise in the skill premium.

The first row of Table 4 summarizes the results of this decomposition exercise. As the table depicts, the traditional channels of skill-biased technical change along with the change in relative supply of skilled labor can explain a bulk of the rise in skill premium. However, interestingly, the change in individual level risk also explains a substantial level of the change. The changes in tax and debt policy seem to have a smaller effect.

Recall that the column 'Traditional' summarizes the cumulative effect of the decline in the price of equipment capital (skill-biased technical change) and the increase in the supply of skilled workers. Intuitively, when the price of equip-

23

Table 4: Decomposing Changes in Inequality

|  | Traditional | Policy | Risk |
|---|---|---|---|
| Skill premium | 84% | 7% | 9% |

|  | Risk | Policy | Traditional |
|---|---|---|---|
| Skill premium | 17% | 7% | 76% |

This table decomposes the changes in skill premium to changes that are coming from traditional channels (skill-biased technical change and change in relative supply of skilled workers), changes in policy, and changes in individual labor income risk.

ment capital decreases, more equipment capital is accumulated in the new steady state. This increases the demand for skilled agents endogenously due to capital-skill complementarity. 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.[8] The second column of Table 4 shows that 84% of the total 0.38 percentage points change in the skill premium that the model generates is due to the changes in the traditional channels.

Interestingly, as the last column in Table 4 shows, the increase in residual wage risk also adds substantially to the rise of the skill premium. In particular, 9% of the total model generated change in skill premium is due to the rise of individual level wage risk. The mean of the productivity processes are normalized to one both in 1960's and 2000's distributions, and thus, holding the amount of inputs to production 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. An increase in residual wage risk leads to higher precautionary savings and thus

---

[8]See Goldin and Katz (2008). The race terminology is originally due to Tinbergen (1974).

to higher levels of aggregate capital (we find that, in this exercise, the aggregate capital stock increases by about 11% due to changes in labor income risk). 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 observe that a decline in capital taxes and a rise in government debt together generate 7% of the total increase in the skill premium. The decline in capital taxes leads to larger capital accumulation, and hence to an increase in the skill premium. This effect is partially offset by the increase in government debt, which crowds out capital accumulation.

In the decomposition exercise reported in the first row of Table 4, we start from 1960's economy and add changes in traditional channels, government policies, and risk in that order. It turns out that the contribution of each of these factors to the change in the skill premium depends - somewhat undesirably - on the order these changes are introduced. In an alternative exercise that is reported in the second row of Table 4, we first introduce the change of risk on the 1960's economy and find out that the rise in risk alone can explain a rise of the skill premium from 1.52 to 1.59. This is about 17% of the total change in skill premium. This increase is larger than in the previous exercise, because the change in labor income risk leads to a larger, 14%, increase in aggregate capital. Traditional channels still explain the lion's share of the change in skill premium whereas change in policy is the least important factor.

## 4.4 Permanent vs. Transitory Component

We have shown in the previous section that changes in labor income risk are quantitatively important for the aggregate amount of capital in the economy and hence

25

Table 5: Decomposition between Persistent and Transitory Components

|  | 1960's | 2000's | Risk overall | Persistent component | Transitory component |
|---|---|---|---|---|---|
| Skill premium | 1.524 | 1.898 | 1.587 | 1.582 | 1.528 |
| Δ capital |  | 122.8% | 14.2% | 11.4% | 2.5% |
| Var log wages | 0.23 | 0.54 | 0.48 | 0.44 | 0.27 |

This table compares the evolution of variable of interest for the benchmark quantitative exercise (column '2000's'), the exercise in which only risk changes (column 'Risk overall') and the exercises in which only the persistent shock variance changes (column 'Persistent component') and only the transitory component changes (column 'Persistent component').

for the skill premium. The wage process we use has two shocks, a transitory shock and a highly persistent shock. Consistent with the empirical estimates of Heathcote, Storesletten, and Violante (2010), we assume that the variances of both these shocks increased between the 1960's and the 2000's. A natural question is to ask which of the two components was more important in accounting for the changes in the skill premium. This is precisely what this section does. We use the second decomposition exercise from the previous section, i.e., we take the calibrated 1960's economy, assume the rest of the parameters remains constant and change separately the variance of the persistent and the variance of the transitory component. We then compute the new steady states and compare them with the one in which we changed the variances of both components.

These results are reported in Table 5. As we see, the change in the persistent component explains most of the changes in skill premium that is coming from changes in risk. The reason is that the impact of changes in the persistent component on precautionary savings and thus aggregate capital is much larger, as reported in second row of Table 5. The reason for this difference between the impact of the change in the persistent vs. the change in the transitory component appears to be that the increase in the volatility of the persistent component has a much

Table 6: Change in Overall Inequality

|  | Data | | | Model | | |
|---|---|---|---|---|---|---|
|  | 1960's | 2000's | Change | 1960's | 2000's | Change |
| Var of log wages | 0.27 | 0.46 | 0.19 | 0.23 | 0.54 | 0.31 |
| Wage Gini | 0.29 | 0.39 | 0.12 | 0.27 | 0.40 | 0.13 |
| Varlog of Earnings | 0.43 | 0.69 | 0.26 | 0.32 | 0.75 | 0.43 |
| Earnings Gini | 0.35 | 0.44 | 0.09 | 0.32 | 0.46 | 0.14 |

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).

larger impact of the level of wage volatility and hence wage risk, as documented in the last row of the Table 5.

## 4.5   Changes in Overall Inequality

This section evaluates the model's success in explaining the observed changes in wage and earnings inequality in the United States between the 1960's and the 2000's. Table 6 summarizes the main findings. All the data values in Table 6 are taken from Heathcote, Perri, and Violante (2010). First, we want to see how well the model matches the level of inequality in the 1960's. A comparison of the first and fourth columns (data and model) regarding the first and second rows shows that the model does quite well in matching the observed wage inequality in the 1960's. Comparing the third and fourth rows show that the model is doing well also in matching observed earnings inequality for the same time period.

Second, Table 6 also reports how well the model does in matching the change in inequality during the period of interest. A comparison of the third and the sixth columns of Table 6 reveals that the model somewhat overestimates the increase in overall inequality in wages and earnings.

## 4.6 Risk Aversion and Labor Supply Elasticity

Changes in the level of idiosyncratic productivity risk affect the skill premium through changes in precautionary savings. This suggests that the strength of this channel should depend on the degree of risk aversion. This is indeed what we find, as shown in Table 7. Each row in Table 7 reports the contribution of the risk channel to the rise in skill premium for different degrees of risk aversion. The fourth column shows that, when risk aversion is low ($\sigma = 0.5$), then the skill premium in the model in which all factors but risk are changed to their 2000's levels give a rise in skill premium to 1.74 whereas the model in which all factors change features a skill premium of 1.75. This implies that the marginal contribution of risk in explaining the rise in skill premium over other factors is 6%, as reported in the fifth column report. This number is 9% in the benchmark case of $\sigma = 1$ and rises to 13% when $\sigma = 2$. The last two columns report an alternative way of measuring the contribution of the rise in risk to the rise in skill premium. Here, we only impose the change in risk to the 1960's economy and compute the changes in skill premium. The last column shows that also under this alternative measure the importance of the risk channel increases with risk aversion. Importantly, the increase in wage risk is a significant contributor to the rise in skill premium in all the three cases.

Finally, a comparison of the first two columns of the table for different degrees of risk aversion shows that the case of $\sigma = 0.5$ falls short of generating the observed increase in the skill premium while the case of $\sigma = 2$ generates an increase in the skill premium larger than in the data. The obvious reason for this is that, with higher degree of risk aversion, precautionary savings increase which leads to higher capital accumualtion and therefore skill premium. This effect is also re-

Table 7: Risk Aversion

| $\sigma$ | 1960's | 2000's | All but risk | Contribution of risk | Only risk | Contribution of risk |
|---|---|---|---|---|---|---|
| 0.5 | 1.52 | 1.75 | 1.74 | 6% | 1.55 | 12% |
| 1 | 1.52 | 1.90 | 1.87 | 9% | 1.59 | 17% |
| 2 | 1.52 | 2.19 | 2.11 | 13% | 1.68 | 23% |

This table reports the changes in skill premium as a function of agents' risk aversion, $\sigma$. Column '1960's' shows the properties of the model in the initial steady state, column '2000's' in the new steady state in which all factors have changed. Column 'All but risk' shows the skill premium in the new steady state if all factors changed, but labor income risk remained at the 1960's level. The next column 'Contribution of risk' measures the marginal contribution of changes in risk when all other factors have changed. The column 'Only risk' shows the skill premium in the new steady state if wage risk is the only factor that has changed. The next column 'Contribution of risk' measures the marginal contribution of changes in risk when none of the other factors have changed.

inforced by the fact that with $\sigma > 1$, the income effect of wage changes on labor supply dominates the substitution effect. Between the 1960's and the 2000's wages of the skilled have grown more than wages of the unskilled. Therefore, the skilled decrease their labor supply more than the unskilled. This further increases the skill premium. The logic is opposite when $\sigma < 1$. Importantly, our benchmark case of $\sigma = 1$ generates an increase in the skill premium that very close to the data.

Table 8 reports the same set of results as Table 7, but for different degrees of labor supply elasticity, $\gamma$, rather than for different degrees of risk aversion. This table shows that our main results are robust to changes in labor supply elasticity. The overall increase in the skill premium is approximately 38 percentage points on all three versions of the model. The contribution of the risk channel is between 8% and 10% when the change in risk is added last (the fifth column of the table) and between 15% and 19% when it is added first (the last column of the table).

Table 8: Labor Supply Elasticity

| $\gamma$ | 1960's | 2000's | All but risk | Contribution of risk | Only risk | Contribution of risk |
|---|---|---|---|---|---|---|
| .5 | 1.52 | 1.90 | 1.86 | 10% | 1.59 | 19% |
| 1 | 1.52 | 1.90 | 1.87 | 9% | 1.59 | 17% |
| 2 | 1.52 | 1.90 | 1.87 | 8% | 1.58 | 15% |

This table reports the changes in skill premium as a function of the inverse of agents' labor supply elasticity, $\gamma$. Column '1960's' shows the properties of the model in the initial steady state, column '2000's' in the new steady state in which all factors have changed. Column 'All but risk' shows the skill premium in the new steady state if all factors changed, but labor income risk remained at the 1960's level. The next column 'Contribution of risk' measures the marginal contribution of changes in risk when all other factors have changed. The column 'Only risk' shows the skill premium in the new steady state if wage risk is the only factor that has changed. The next column 'Contribution of risk' measures the marginal contribution of changes in risk when none of the other factors have changed.

# 5  Small Open Economy

The United States is not literally a closed economy, but following the literature, we consider that scenario a useful benchmark. This section illustrates to what extent our results depend on the assumption of closed economy. First, we investigate whether our model's success in replicating the observed change in the skill premium survives if we instead model the United States as an open economy. Second, we analyze whether the rise in individual wage risk is still a quantitatively significant factor in causing the skill premium to rise if one assumes that the United States is an open economy.

We model United States as a *small* open economy that faces an exogenous world interest rate. The procedure for calibrating the model to the 1960's U.S. economy is the same as before, with one additional parameter to choose, namely the world interest rate. We choose the world interest rate to match the international investment position (IIP) of the U.S. in the 1960's. The IIP is only reported in the National

Table 9: Small Open Economy

|  | 1960's closed | 2000's closed | 1960's open | 2000's open | Only IIP |
|---|---|---|---|---|---|
| Skill premium | 1.52 | 1.90 | 1.52 | 1.90 | 1.53 |
| Total capital | 0.81 | 1.80 | 0.81 | 1.82 | 0.81 |
| Net domestic assets | 0.81 | 1.80 | 0.84 | 1.72 | 0.76 |
| Foreign assets | 0 | 0 | -0.03 | 0.10 | 0.05 |
| After tax return | 1.13% | 0.84% | 1.13% | 0.81% | 1.12% |

This table reports the changes in skill premium assuming US is a small open economy. Net domestic assets refer to total domestic savings minus government debt.

Income and Product Accounts (NIPA) from year 1976 onwards, when it is around 10% of the U.S. GDP (i.e., in net terms Americans were holding a large amount of assets abroad). According to Howard (1989) (see Figure 1 on page 1a), this is also a good approximation for the 1960's. The calibrated value for the net world real interest rate is 1.13%.

The exercise we conduct to compute the overall change in skill premium is very similar to the one we do in the benchmark closed economy case with one important difference: in addition to the changes in the traditional channels, wage risk, and government policy, we also model the change in international asset markets by making sure that we match the net IIP of the US economy for the 2000's. We do this by choosing the world interest rate in the 2000's to match the IIP of the United States, which is computed to be -17.5% of U.S. GDP (this is the average between 2001-2005) for 2000's. The resulting world interest rate is 0.81%.

The results of the small open economy exercise are reported in the third and fourth columns of Table 9. For comparison purposes we also report the closed economy exercise in the first and second columns. The skill premium increases from the calibrated value of 1.52 to 1.90 in the open economy exercise which is

almost identical to the change we observe in the benchmark closed economy exercise.[9] One might find this surprising because, as the fourth row of Table 9 shows, the open economy model takes into account that the assets held in the U.S. economy by foreigners (line 'Foreign assets') increases from -0.03 to 0.10 (from -10% to 17.5% of GDP) between the 1960's and the 2000's. One might expect that this inflow of foreign savings, which by definition cannot happen in a closed economy, would induce a larger increase in the amount of capital stock in the open economy relative to the closed economy. This, in turn, would imply a larger increase in the skill premium in the open economy due to the capital-skill complementarity. This does not happen, however, because, as the third row of the Table 9 shows, domestic savings in the open economy in 2000's are smaller than domestic savings in the closed economy, because the interest rate is smaller in the open economy (consistently with the capital inflow). Thus, we conclude that whether one interprets the U.S. as a closed or a small open economy does not change model's prediction regarding the overall rise in skill premium.[10]

In a related exercise, we investigate the effect of changes in international asset markets on the skill premium in the United States. We do so by changing the net foreign asset position of the 1960's US economy to its level in the 2000's and keeping everything else constant. This exercise is reported in the fifth column of Table 9. The resulting skill premium is about 1.53, which means skill premium does not respond much to changes in the international asset markets (more precisely, the skill premium increases from 1.5244 to 1.5270). This is again because the inflow of foreign savings in the U.S. economy depresses the interest rate and thereby do-

---

[9]To be precise, in the closed economy skill premium goes up to 1.898 whereas in the open economy it goes up to 1.901.

[10]See Heathcote, Storesletten, and Violante (2010) for a related point.

mestic savings. As a result, total capital stock goes up much less than the increase in foreign assets might suggest.

The second question we want to answer is whether our result that the rise in individual wage risk is an important factor in causing the rise of the skill premium between 1960's and 2000's is valid if the U.S. is an open economy. We investigate this issue as follows. We take the small open economy version of the model for the 2000's, which implies a world interest rate of 0.81% and a skill premium of 1.9011. We then solve an alternative version of the model, in which we ignore the changes in risk (i.e., keep risk at its 1960's level), but for the other factors, we use their 2000's values. We also use the interest rate of 0.81% needed to rationalize the capital inflows in the benchmark 2000's open economy exercise. The difference in the skill premium between these two economies measures the marginal contribution of the rise in risk in a small open economy with a fixed interest rate. We find that the skill premium for the second economy is 1.9040, which is virtually the same as the skill premium for the benchmark 2000's open economy exercise in which we model all the changes between 1960's and 2000's including the change in risk.

This result is expected. The assumption that the United States is a *small* open economy that faces an exogenous interest rate implies that the level of domestic savings in the U.S. economy has virtually no effect on the level of capital stock in the United States. The world interest rate pins down the level of capital, and U.S. aggregate savings only affect how much of that domestic capital is financed by domestic savings. In other words, domestic savings only affect the international investment position of the U.S. Since the link between domestic savings and capital accumulation is broken, the rise in individual wage risk does not have an effect on capital accumulation and on the skill premium.

The important question is whether the small open economy assumption is appropriate for the US economy. In the exercise just described, the U.S. IIP is -2.64 as a fraction of U.S. GDP. This means that the United States would borrow much more (2.639 times its GDP vs. 0.175 times) if the wage risk in the U.S. economy had not gone up (since domestic savings would be lower) and the US was a small open economy. However, such a large increase in U.S. borrowing would probably increase the world interest rate (the rate at which US economy would borrow at the international asset markets), which then would reduce capital accumulation. As a result, skill premium would have gone up less if there was no increase in wage risk. We conclude that, for a proper quantitative assessment of how much the observed rise in individual wage risk has contributed to the rise in skill premium in an open economy context, one should model the U.S. as a *large* open economy, rather than a *small* open economy. This is what we plan to do next.

## 6   Conclusion

This paper first shows that the observed changes in skill premium can be well explained by a model that incorporates the technology-education race model of Tinbergen (1974) into a standard incomplete markets model. Second, this paper decomposes the changes in the skill premium into three components coming from changes in: traditional channels individual wage risk, and tax policy. We find that even though traditional channels of skill-biased technical change and the change in the relative supply of skilled workers along with changes in government policy explain a large fraction of the rise in the skill premium, a significant fraction of this change is due to the rise in the wage risk that workers face.

# References

ACEMOGLU, D., AND D. AUTOR (2011): *Skills, Tasks and Technologies: Implications for Employment and Earnings*vol. 4 of *Handbook of Labor Economics*, chap. 12, pp. 1043–1171. Elsevier.

AIYAGARI, S. R. (1994): "Uninsured Idiosyncratic Risk and Aggregate Saving," *The Quarterly Journal of Economics*, 109(3), 659–84.

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.

BEWLEY, T. F. (1986): "Stationary Monetary Equilibrium with a Continuum of Independently Fluctuating Consumers," in *Contributions to Mathematical Economics in Honor of Gerard Debreu*, ed. by W. Hildenbrand, and A. Mas-Colell, vol. 1, pp. 79–102. Amsterdam: North-Holland.

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.

GOTTSCHALK, P., AND R. MOFFITT (1994): "The Growth of Earnings Instability in the U.S. Labor Market," *Brookings Papers on Economic Activity*, 25(2), 217–272.

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.

HOWARD, D. D. (1989): "The United States as a Heavily Indebted Country," International Finance Discussion Papers 353, Board of Governors of the Federal Reserve System.

HUGGETT, M. (1993): "The risk-free rate in heterogeneous-agent incomplete-insurance economies," *Journal of Economic Dynamics and Control*, 17(5-6), 953–969.

IMROHOROGLU, A. (1989): "Cost of Business Cycles with Indivisibilities and Liquidity Constraints," *Journal of Political Economy*, 97(6), 1364–83.

KAYMAK, B., AND M. POSCHKE (2015): "The Macroeconomic Implications of Cuts in Top Income Tax Rates: 1960-2010," Carnegie-rochester-nyu conference on public policy on "inequality, institutions, and redistribution,".

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.

SABELHAUS, J., AND J. SONG (2010): "The great moderation in micro labor earnings," *Journal of Monetary Economics*, 57(4), 391–403.

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