Wage Risk and the Skill Premium

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The skill premium has gone up significantly in the United States in the last five decades. During the same period, individual wage volatility has also increased. By incorporating the technology-education race model of Tinbergen (1974) into a standard incomplete markets model, this paper proposes a mechanism through which a rise in individual wage risk leads to an increase in skill premium. In our benchmark quantitative exercise, the rise in individual wage risk observed between 1967 and 2010 accounts for about 1/3 of the overall increase in skill premium during the same period.

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1 Introduction

The substantial increase in the wages of college graduates relative to those without college education, the skill premium, is one of the most notable inequality trends observed in recent decades. 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 the 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. In this paper, we point out a link between the rise in individual wage risk and the rise in skill premium. Specifically, we propose mechanism through which a rise in individual wage risk leads to an increase in skill premium and show that this mechanism can be quantitatively significant. 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

[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.

use to study inequality.

More specifically, we build an infinite horizon macroeconomic model with heterogeneous agents with the following three key features. First, agents are either skilled or unskilled. Second, within each skill group, agents are subject to (skill-specific) 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 match the skill premium and certain other moments of the 1967 U.S. economy. Then, we feed in the change in individual wage risk, price of equipment capital, the relative supply of skilled labor and government policy that is observed between 1967 and 2010, and assuming that the U.S. economy converges to a new steady in 2010, compute this new steady state. We find that our model generates a 36 percentage point increase in the skill premium, from 1.51 in 1967 to 1.87 in 2010. This is a good match of the 39 percentage point rise in skill premium observed during the same time period.

Next, we turn to our main question of interest: the effect of the rise in wage risk on the skill premium. We conduct a counterfactual exercise in which we feed in the observed change in individual wage risk but keep all other factors in their 1967 levels. We find that the increase in wage risk increases the skill premium by 13 percentage points, or roughly by a third of the overall 39 percentage point increase observed between 1967 and 2010. 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.

In our benchmark analysis, we assume that the fraction of skilled and unskilled agents are fixed since our main focus in this paper is on the relative prices of labor given observed relative supply of skilled agents. In Section 5, we provide an alternative measure of how much the rise in wage risk affects the skill premium which takes into account the effect of the rise in risk on people's education decisions. We find that the effect of the rise of wage risk on skill premium in the case where people are allowed to adjust their education decisions upon experiencing the rise in risk is of comparable magnitude to the case in which skill supply is fixed.

In the baseline model, we treat the United States as a closed economy. In Section 6, we analyze to what extent our results depend on the closed economy assumption. First, we find that whether one models the United States as a closed economy or as a large open economy does not change the model's prediction regarding the overall rise in the U.S. skill premium. Second, we find that in the large open economy model the rise in U.S. wage risk still contributes to the rise in the U.S. skill premium significantly. Finally, we find that the change in the saving behavior of the foreigners, the so-called "savings glut", also contributes to the rise in the U.S. skill premium, albeit to a lesser degree than the rise in wage risk.

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 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 quantitative findings. In Section 5 and Section 6, we consider endogenous skill supply and open economy extensions. Section 7 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.

Demographics. The total population size is assumed to be unity. We adopt a version of the Yaari (1965) perpetual youth model in which agents are born at age zero and survive from age h to age $h+1$ with constant probability $\delta < 1$. A new generation with mass $(1-\delta)$ enters the economy at each date t with zero asset holdings. Assets of deceased people are distributed among the survivors proportional to the survivors' wealth. This is equivalent to assuming that people can buy actuarially fair life insurance policy. We do not model life before labor market entry and assume all agents enter the labor market at the real life age of 25. Therefore, model age of 0 corresponds to real life age of 25.

Skill Heterogeneity and Productivity Shocks. Ex-ante, agents differ in their skill levels: they are born either skilled or unskilled, $i \in \{s, u\}$, and remain so until the end of their lives. Skilled agents can only work in the skilled labor sector and unskilled agents only in the unskilled labor sector. Agents of skill type i receive a wage rate w_i for each unit of effective labor they supply. The total mass of the skilled agents is denoted by π_s and the total mass of the unskilled agents is denoted by π_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 π_s to increase from its value in 1967 to that in 2010.

In addition to heterogeneity between skill groups, there is ex-post heterogeneity *within* each skill group because agents face idiosyncratic labor productivity shocks every period. Agents who belong to skill group i draw their productivity shocks independently from one another according to the stochastic process z_i. Notice that we allow for the stochastic processes that govern the productivity shocks hitting the two skill groups to be different. We model the logarithm of z_i as the sum of two orthogonal components: a persistent autoregressive shock and a transitory shock. More precisely,

$$\log z_{i,t} = \theta_{i,t} + \varepsilon_{i,t},$$
$$\theta_{i,t} = \xi_i \theta_{i,t-1} + \kappa_{i,t},$$

where $\varepsilon_{i,t}$ and $\kappa_{i,t}$ are drawn from distributions with mean zero and variances $\sigma_{i,\varepsilon}$ and $\sigma_{i,\kappa}$. ξ_i represents the persistence parameter of the AR(1) process that governs the persistent component. Agents draw initial value of the persistent component of their labor productivity at age $h = 0$ from a distribution with mean zero and variance $\sigma_{i,\theta}$. For notational simplicity, we define the vector of idiosyncratic productivity components by $\mathbf{z_i} = (\theta_i, \varepsilon_i) \in \mathcal{Z}_i$.

In Section 4, we model the change in idiosyncratic wage risk by changing variances $\sigma_{i,\varepsilon}$ and $\sigma_{i,\kappa}$ from their values in 1967 to those in 2010. Notice that since both the persistent and transitory components of the shocks are zero for both skill groups in both steady states, average value of z_i is one. Thus, skill premium in the model economy is given by w_s/w_u in both steady states.

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

$$E_i \Big[\sum_{h=0}^{\infty} (\beta\delta)^h u(c_{i,h}, l_{i,h}) \Big],$$

where β is the time discount factor. The function $u(\cdot)$ is strictly increasing and concave in consumption and strictly decreasing and convex in labor. The unconditional expectation, E_i is taken with respect to the stochastic processes governing the idiosyncratic labor shock for agent of skill type i. 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. Excluding labor supply responses would affect agents' precautionary savings and could overstate the importance of changes in wage risk.

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 δ_s and δ_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 1967 level to 2010 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:

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

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. Define $\mathcal{A} = [0, \infty]$ as the set of possible asset levels that agents can hold. 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 1967 and another one to the 2010. 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). Let $\mathcal{B}_{\mathcal{A}}$ and $\mathcal{B}_{\mathcal{Z}_i}$ denote Borel $\sigma-$algebras of the sets $\mathcal{A}$ and $\mathcal{Z}_i$ for $i = \{s, u\}$. The state space for type i is defined as $s_i = (\mathbf{z_i}, a) \in \mathcal{S}_i = (\mathcal{Z}_i, \mathcal{A})$. Let $\mathcal{B}_{\mathcal{S}_i} = \mathcal{B}_{\mathcal{A}} \times \mathcal{B}_{\mathcal{Z}_i}$ be the Borel $\sigma-$algebra of the set $\mathcal{S}_i$.

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 λ_u, λ_s 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 $i \in \{u, s\}$:

$$\begin{aligned} V_i(\mathbf{z_i}, a_i) = \max_{\{c_i, l_i, a_i'\}} & \quad u(c_i, l_i) + \beta\delta E_i[V_i(\mathbf{z_i'}, a_i')] \qquad \text{s.t.} \\ (1+\tau_c)c_i + \delta a_i' & \leq w_i z_i l_i - T(w_i z_i l_i) + R a_i, \\ c_i \geq 0, \quad l_i & \in [0,1], \quad a_i' \in A, \end{aligned}$$

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 λ_i is stationary for each type, i.e. $\forall i = \{s, u\}, \forall s_i \in \mathcal{S}_i, \forall S_i = (Z_i, A) \in \mathcal{B}_{\mathcal{S}_i}$, λ_i satisfies

$$\lambda_i(S_i) = \int_{\mathcal{S}_i} Q(s_i, S_i) d\lambda_i,$$

where

$$Q(s_i, S_i) = \delta I_{\{a_i'(s_i) \in A\}} Pr\{\mathbf{z_i'} \in Z_i | \mathbf{z_i}\} + (1-\delta) I_{\{0 \in A\}} Pr_0\{\mathbf{z_i'} \in Z_i\}$$

and $Pr_0(\cdot)$ is computed according to the initial unconditional distribution of entrants over persistent component θ_i.

4. Markets clear:

$$
\begin{aligned}
\sum_{i=u,s} \pi_i \int_{\mathcal{S}_i} a_i'(s_i) d\lambda_i(s_i) &= K_s + K_e + D, \\
\pi_i \int_{\mathcal{S}_i} z_i l_i(s_i) d\lambda_i(s_i) &= L_i, \quad \forall i \in \{s, u\}, \\
C + G + K_s + K_e &= \tilde{F}(K_s, K_e, L_s, L_u),
\end{aligned}
$$

where $C = \sum_{i=u,s} \pi_i \int_{\mathcal{S}_i} c_i(s_i) d\lambda_i(s_i)$ 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 $T_{agg} = \sum_{i=u,s} \pi_i \int_{\mathcal{S}_i} T(w_i z_i l_i(s_i)) d\lambda_i(s_i)$ 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 1967 technology, relative supply of skilled workers, residual wage risk, and taxes coincides with the U.S. economy in the 1967. 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. The internal calibration procedure is summarized in Table 2. 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. Because of data availability reasons, we focus on working age males, when comparing the 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 Balanced Growth Path compatible form

$$u(c,l) = \frac{\left[c^{\phi}(1-l)^{(1-\phi)}\right]^{\frac{1-\sigma}{\phi}} - 1}{\frac{1-\sigma}{\phi}}.$$

Here, σ equals the coefficient of relative risk aversion in consumption. The parameter ϕ together with σ controls the average labor supply and Frisch elasticity of labor. In the benchmark case, we use $\sigma = 2$ and calibrate ϕ to match average labor supply. The resulting Frisch elasticity of labor supply is 1.14 for the agent with the average labor supply in the economy.[2] This value is within the range of reasonable macro labor supply elasticities.

We further assume that the production function takes the form:

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

Krusell, Ohanian, Ríos-Rull, and Violante (2000) estimate α, ρ, η, and we use their estimates. ρ controls the degree of complementarity between equipment capital and skilled labor while η 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 complemen-

[2]Notice that, under this preference specification, the Frisch elasticity of labor supply is not constant and depends on the quantity of labor supplied. More precisely, the Frisch elasticity for an agent who works l hours is equal to $\frac{1-l}{l}\frac{\sigma}{1-\frac{1-\sigma}{\phi}}$.

tarity. They do not report their estimates of ω and ρ. We calibrate these parameters internally as we explain in detail below. We also normalize 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 Heathcote, Storesletten, and Violante (2014) and assume that tax liability given labor income y is defined as:

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

where $\bar{y}$ is the mean labor income in the economy, $1-\chi$ is the average tax rate of a mean income individual, and τ_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 1967 and 2010. We use their estimate and calibrate χ 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 1967, at the firm level the average tax rate on equipment capital was approximately 41% while the average tax

Table 1: Benchmark Parameters for 1967

Parameter	Symbol	Value	Source
Preferences			
Relative risk aversion parameter	σ	2	
Technology			
Structure capital depreciation rate	δ_s	0.056	GHK
Equipment capital depreciation rate	δ_e	0.124	GHK
Share of structure capital in output	α	0.117	KORV
Measure of elasticity of substitution between equipment capital K_e and unskilled labor L_u	η	0.401	KORV
Measure of elasticity of substitution between equipment capital K_e and skilled labor L_s	ρ	-0.495	KORV
Fraction of skilled workers in 1967	π_s^{67}	0.1356	CPS
Redisual Wage Risk			
Skilled agents			
Persistence of the AR(1) component	ξ_s	0.9834	HSY
Variance of the transitory shock in 1967	$\sigma_{s,\varepsilon}^{67}$	0.0116	HSY
Variance of the persistent shock in 1967	$\sigma_{s,\kappa}^{67}$	0.0037	HSY
Variance of the persistent component for entrants	$\sigma_{s,\theta}$	0.1172	HSY
Unskilled agents			
Persistence of the AR(1) component	ξ_u	0.9859	HSY
Variance of the transitory shock in 1967	$\sigma_{u,\varepsilon}^{67}$	0.0177	HSY
Variance of the persistent shock in 1967	$\sigma_{u,\kappa}^{67}$	0.0052	HSY
Variance of the persistent component for entrants	$\sigma_{u,\theta}$	0.1488	HSY
Government polices			
Labor tax progressivity in 1967	τ_l	0.185	HSV (2014)
Overall structure capital tax in 1967	τ_s	0.5665	Auerbach (1983)
Overall equipment capital tax in 1967	τ_e	0.4985	Auerbach (1983)
Consumption tax	τ_c	0.05	MTR
Government consumption	G/Y	0.16	NIPA
Government debt in 1967	D/Y	0.39	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), HSY, 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), Hong, Seok, and You (2015), 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.

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 set government debt of 39% of GDP for 1967 as reported by the Federal Reserve Bank of St. Louis Database.

We calculate the fraction of skilled agents in 1967, π_s^{67}, to be 0.1356 using the Current Population Survey (CPS) data. 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).

Recall that in the model skilled and unskilled agents are allowed to have different stochastic processes for labor productivity shocks. Moreover, the stochastic process for each skill group is modelled as the sum of a persistent autoregressive component and a transitory component. Hong, Seok, and You (2015) uses Panel Study of Income Dynamics data and estimate for each skill group separately the variance of the shocks persistent component $(\sigma_{i,\kappa})$, variance of the shocks to transitory component $(\sigma_{i,\varepsilon})$, and the persistence parameters (ξ_i) for all years between 1967 and 2010 assuming that the persistence parameters are time-invariant. The estimated parameters are very volatile across years. For that reason, for each parameter, we take the average of the estimated values for the five years between 1967 and 1971 and set the parameter value for 1967 steady state to this average. We approximate these processes by finite number Markov chains using the Rouwenhorst method described in Kopecky and Suen (2010). The variances of the initial distributions of the persistent component for both skill groups, $\sigma_{i,\theta}$, are also taken from Hong, Seok, and You (2015). All these parameter values regarding idiosyncratic productivity shocks are reported in the Productivity segment of Table 1.

There are still five parameter values left to be assigned: these are the two production function parameters, ω and ν, which govern the income shares of equipment capital, skilled labor and unskilled labor, the utility parameter ϕ, the discount factor β, and the parameter governing the overall level of taxes in the tax function, χ. We calibrate ω and ν 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 1.51 (as reported by Heathcote, Perri, and Violante (2010) for 1967 for males aged 25-60 with at least 260 working hours per year). We choose ϕ so that the aggregate labor supply in steady state equals 1/3 (as is commonly assumed in the macro literature). We calibrate β 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 χ to clear the government budget constraint in equilibrium. Table 2 summarizes our calibration procedure.

4 The Effect of Wage Risk on Skill Premium

In this section, we assess the quantitative significance of our mechanism by measuring how much of the overall increase in U.S. skill premium between 1967 and 2010 it can account for. To do so, we first summarize the changes in residual wage risk and skill premium during this period. Next, we describe the changes in other factors that are expected to affect the skill premium such as the skill-biased techni-

Table 2: Internally Calibrated Parameters for 1967

Parameter	Symbol	Value	Target	Data & SRCE	Source
Production parameter	ω	0.8333	Labor share	2/3	NIPA
Production parameter	ν	0.4122	Skill premium in 1967	51%	HPV
Disutility of labor	ϕ	0.3985	Labor supply	1/3	
Discount factor	β	1.0131	Capital-to-output ratio	2.9	NIPA, FAT
Tax function parameter	χ	0.8708	Gvt. budget balance		

This table reports our benchmark calibration procedure. The production function parameters ν and ω control the income share of equipment capital, skilled and unskilled labor in output. The tax function parameter λ 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.

cal change, relative supply of skilled workers, and government policy. Finally, we evaluate the effect of the rise in residual wage risk on the skill premium using our model.

4.1 Changes in Wage Risk and the Skill Premium

The skill premium in the United States has gone up by a significant margin between 1967 and 2010. Heathcote, Perri, and Violante (2010) uses CPS data to compute skill premium for the period 1967-2005 for males between ages of 25 and 60, working at least 260 hours a year. We use their methodology and extend the time series of skill premium till 2010. Our calculations show that skill premium has been roughly constant during 2005-2010 period and is equal to 1.9 in 2010.[3]

During the same time period, the U.S. economy has also experienced a significant increase in residual wage risk. Table 3 below reports the dramatic rise in the estimates of the variances of both persistent and transitory shocks provided

[3]This is in line with Autor (2014) who also finds that skill premium has flattened out during the same period.

Table 3: Changes in Wage Risk between 1967 and 2010

Parameter	1967	2000
Skilled agents		
Variance of the transitory shock	0.0116	0.0673
Variance of the persistent shock	0.0037	0.0304
Unskilled agents		
Variance of the transitory shock	0.0177	0.0627
Variance of the persistent shock	0.0052	0.0157

The values reported in the table are from Hong, Seok, and You (2015).

by Hong, Seok, and You (2015) between 1967 and 2010. Due to high volatility of the estimates over time, we set the 2010 value of each variance to the average of the last three observations (2006, 2008, and 2010). Notice also that the persistence parameter of the AR(1) process governing the persistence component of wage risk is not reported in the table since it is assumed to be time-invariant. Similarly, the initial distribution of the persistent component from which the entrants make their initial draws is also assumed to be constant over time.

Before we discuss our findings, in Section 4.2 below, we first describe in detail the changes in factors other than risk that might have affected the skill premium between the 1967 and the 2010.

4.2 Changes in Other Factors

This section documents the changes in technology, relative supply of skilled workers, residual wage volatility, and labor income taxes between the 1967 and the 2010.

Technology. Our measure of technological improvement (skill-biased technical change) is the change in the relative price of equipment capital, q, between 1967 and 2010. Following the methodology of Cummins and Violante (2002), DiCecio

(2009) documents that the price of equipment capital in consumption good units has decreased from the normalized value of 1 in 1967 to 0.1577 in 2010.

Since different types of labor have different elasticity of substitution with equipment capital, the decline in the relative price of equipment capital endogeneously implies a change in the skill premium, i.e., skill-biased technical change. In the calculations provided by DiCecio (2009), 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 1967 price of 1.

Supply of skilled workers. We compute the fraction of skilled workers for 2010 following the same procedure we used to compute it for 1967. As before, we only consider males who are 25 years and older and who have earnings. We find that the fraction of skilled workers increased from 0.1356 in 1967 to 0.3169 in 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 26% in the 2010. 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 2010 while in the 1967 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 in 1967 to 0.89 in 2010.

We keep government consumption as a fraction of GDP constant between 1967 and 2010, because it is fairly constant in the data. We also assume that the progressivity of the labor tax code has not changed between 1967 and 2010. We do so because existing estimates of progressivity rely on the TAXSIM program, which does not include state taxes prior to 1978 and, hence, labor tax progressivity for 1967 cannot be properly measured.[4] 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 χ, which is set so that the government budget clears in the new steady state.

4.3 Quantitative Significance of the Mechanism

In this section, we first feed in the changes in key factors that we expect to have an impact on the skill premium including the change in wage risk and assess how much of the changes in skill premium that we observe in the data our model can explain. Then, we conduct two counterfactual exercises to measure the contribution of the rise in wage risk to the rise in skill premium.

Table 4 summarizes the model's success in explaining the observed changes in the skill premium in the United States between 1967 and 2010. Looking at Table 4, we first notice that the model generates the exact value of skill premium in 1967. This is not surprising as the value of skill premium in 1967 is a target of the calibration procedure. 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 2010: it undershoots the level of skill premium in 2010 by only three percentage points. Restated in terms of changes, the model does a good job in replicating the rise in skill premium: 39 percentage points in the data vs. 36 percentage points in the model.

Having checked the success of the model in replicating the observed rise in skill

[4]Kaymak and Poschke (2015) try to overcome the issue and estimate that $\tau_l = 0.08$ in the 1967 and $\tau_l = 0.17$ in the 2010. 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 significant impact on neither the skill premium nor on how important changes in labor income risk are.

Table 4: Change in Skill Premium between 1967 and 2010

	Data			Model		
	1967	2010	Change	1967	2010	Change
Skill premium	1.51	1.90	0.39	1.51	1.87	0.36

This table compares the actual and model generated levels of and changes in skill premium between 1967 and 2010. 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.

premium between 1967 and 2010, we can now use the model to perform counterfactual analyzes that allow us to attribute changes in the skill premium to changes in residual wage risk.

We perform two different counterfactual analyzes. First, we compute a steady-state equilibrium of the model economy where we feed in the structure of wage risk in 2010 but keep all other factors at their 1967 levels. A comparison of the skill premium of this economy with the skill premium in 1967 reveals how much of the total change in skill premium can be accounted for by the change in wage risk only. We call this counterfactual exercise the "only risk" exercise. Alternatively, we also feed in the observed changes in all other factors keeping the structure of the wage risk as it is in 1967. A comparison of the skill premium in the resulting economy with the skill premium in 2010 measures how short the model falls of reaching its potential when we exclude the change in wage risk. We call this counterfactual exercise "all but risk".

Table 5 shows that the increase in residual wage risk has a quantitatively significant effect on the skill premium. Depending on the counterfactual analysis, the rise in wage risk generates 13 or 8 percentage points increase in the skill premium. This amounts to 34% or 20% of the total 39 percentage point rise in skill premium observed between 1967 and 2010. The change in residual wage risk affects the skill

Table 5: Effect of Changes in Wage Risk on Skill Premium

	1967	2010	Only Risk	All but Risk
Skill premium	1.51	1.87	1.64	1.79
Contribution			0.13	0.08

This table reports the results of two counterfactual exercises aimed at measuring the effect of changes in wage risk on the skill premium.

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 to higher levels of equipment capital. Due to equipment-skill complementarity present in the production function, this leads to an increase in the skill premium. To verify that this is how the mechanism works, we compute the change in equipment capital stock that occurs due to the rise in risk. We find that the stock of equipment capital increases by 21% in the exercise in which we only increase risk. In the exercise in which we change all factors but keep wage risk at its 1967 level, we find that the level of aggregate capital falls 19% short of the exercise in which we change all factors including risk.

4.4 Sensitivity to Risk Aversion

In the mechanism we propose, the link between wage risk and skill premium works through precautionary savings. It is then natural to think that the strength of this mechanism may depend on the degree of risk aversion. The aim of this section, therefore, is to measure how sensitive our results are to the degree of risk aversion. To this end, we repeat our main exercise for relative risk aversion coefficients of $\sigma = 1$ and $\sigma = 4$, in addition to our benchmark value of $\sigma = 2$. The results are presented in Table 6.

Table 6: Risk Aversion

σ	1967	2010	Only risk	Contribution (%)
1	1.51	1.83	1.57	0.06
2	1.51	1.87	1.64	0.13
4	1.51	1.94	1.80	0.29

This table reports the changes in skill premium as a function of agents' risk aversion, σ. Column '1967' shows the properties of the model in the initial steady state, column '2010' 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 1967 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.

Each row in Table 6 reports our findings for a different level of σ. First, the third column of the table shows that while we undershoot the value of the skill premium in 2010 when the value of σ is 1 and 2, we overshoot it for $\sigma = 4$.

Recall that our main way of investigating the quantitative importance of our mechanism is to run the counterfactual analysis in which we increase the wage risks faced by skilled and unskilled agents to their 2010 values but keep the rest of the parameters of the economy at their 1967 values. The fourth column of Table 6 reports values of skill premium in these exercises for different values of σ. As expected, the contribution of risk increases with an increase in the risk aversion parameter. What is perhaps more surprising is how powerful the mechanism can be for values of the risk aversion parameter that is still within reasonable limits: when $\sigma = 4$, the rise in risk alone is able to generate 29 percentage point increase in skill premium, which corresponds to about 75% of the observed increase between 1967 and 2010.

5 Endogenous Skill Supply

In the baseline environment, we assume that the fraction of skilled and unskilled agents are fixed since our main focus in this paper is on the relative prices of labor given observed relative supply of skilled agents. In particular, in our counterfactual exercise where we feed in the change in risk, we do not allow for skill supply to change. In this section, we provide an alternative measure of how much the rise in wage risk affects the skill premium which takes into account the effect of the rise in risk on people's education decisions. We find that the effect of the rise of wage risk on skill premium in the case where people are allowed to adjust their education decisions upon experiencing the rise in risk is of comparable magnitude to the case in which skill supply is fixed. In the rest of this section, we first explain how we modify the baseline model to incorporate endogenous skill supply. Then, we provide our results.

Education. Agents make education decisions at the beginning of their lives, right before they enter the labor market. They can choose to pursue a college degree in which case they will be called skilled agents, $i = s$, or a lower schooling attainment in which case they will be called unskilled agents, $i = u$. As before, skilled agents can only work in the skilled labor sector and unskilled agents only in the unskilled labor sector. As in Heathcote, Storesletten, and Violante (2010), there is a utility cost of attaining a college degree, ψ, which is idiosyncratic and drawn from a distribution $F(\psi)$. This distribution is a reduced form way of capturing the cross-sectional variation in the psychological and pecuniary costs of acquiring a college degree such as variation in scholastic talent, tuition fees, parental resources, access to credit, and government aid programs.

Upon drawing the cost of education ψ, the agent compares it to the benefit of attaining a college degree, which is simply the net present utility gain of receiving skill premium in every period upon entering the labor market. Let $E_{i,0}[V_i(z_i, 0)]$ be the beginning of life expected utility of an agent who chooses education level i, where the expectation is taken over the set of possible productivity realizations at age 0. The benefit of acquiring a college degree is given by $E_{s,0}[V_s(z_s, 0)] - E_{u,0}[V_u(z_u, 0)]$. Therefore, an individual attends college if and only if

$$E_{s,0}[V_s(z_s, 0)] - E_{u,0}[V_u(z_u, 0)] \geq \psi.$$

Since people choose whether to become skilled or not, the fraction of skilled people in the economy, π_s, which was a parameter in the baseline model, becomes a variable here. The rest of the economic environment is identical to the one developed in the model section and hence will not be described here.

To conduct quantitative work, we need to specify a cost distribution for attending college. We assume that the utility cost of attending college is distributed according to an exponential distribution with a pdf of $f(x) = me^{-mx}$ and a cdf of $F(x) = 1 - e^{mx}$. Observe that, for the marginal agent who chooses to go to college, the cost of attending college exactly equals the benefit of doing so, $\bar{\psi} := E_{s,0}[V_s(z_s, 0)] - E_{u,0}[V_u(z_u, 0)]$. Moreover, the total measure of agents who face an education cost that is at most $\bar{\psi}$ is equal to π_s^{67} in 1967. Then, we calibrate m by setting $F(\bar{\psi}) = \pi_s^{67}$.

In the counterfactual exercise in which we only increase risk, the rise in wage risk observed between 1967 and 2010 increases skill premium by 9 percentage points, or by 25% of the overall increase in skill premium during the same time period, when people are allowed to respond to the rise in wage risk by adjusting their education behavior. Therefore, we conclude that wage risk has a significant effect on skill premium in the endogenous skill supply case, but to a somewhat lesser degree than in the case with fixed skill supply.

The fact that the quantitative significance of our mechanism is not affected too much by the introduction of endogenous skill supply might be surprising. We know from our baseline analysis that the rise in wage risk increases the benefit of receiving a college degree, receiving skill premium in the labor market, significantly. Therefore, one may expect that, with endogenous skills, a higher fraction of the population may attend college, which may dampen the rise of the skill premium at the first place. This happens, but only to a small extent, because wage risk increases much more for the skilled agents than for the unskilled, and that mitigates the rise in benefit of attending college.

6 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. A notable phenomenon that occurred in global financial markets within our period of interest is the significant drop in the net foreign asset position of the U.S. and the corresponding rise in U.S. assets in global portfolios or the so-called "global imlabances". In passing, we also investigate the effects of global imbalances on inequality in the United States.

We model United States as a large open economy which interacts with another large open economy representing the rest of the world. The rest of the world is modelled as a simple incomplete market economy similar to Aiyagari (1994). We assume that the two economies are linked only through frictionless capital and goods markets; there is no labor mobility across the two countries.

6.1 The Rest of the World Economy

The rest of the world economy is intentionally kept simple. In the rest of the world, labor is inelastically supplied with the following preference specification for consumption

$$u(c) = \frac{c^{1-\hat{\sigma}} - 1}{1 - \hat{\sigma}},$$

where $\hat{\sigma}$ refers to the coefficient of relative risk aversion of the consumers in the rest of the world. Foreign consumers evaluate stochastic sequences of consumption $(\hat{c}_t)_{t=0}^{\infty}$ according to

$$E\Big(\sum_{t=0}^{\infty} (\hat{\psi}\hat{\beta})^t u(\hat{c}_t) \Big),$$

where $\hat{\beta}$ is the discount factor of the rest of the world and $\hat{\psi}$ is an exogenous savings wedge. $\hat{\psi}$ should be thought of as an exogenous parameter the rise in which provides a reduced form way of introducing global imbalances to our model economy. In doing so, we are following the "global savings glut" hypothesis which argues that global imbalances are caused by a shift in the saving behavior in the rest of the world.[5] We will calibrate two values for $\hat{\psi}$, one for the 1967 and another

[5]The savings glut hypothesis was first put forth by Bernanke (2005). The modeling of savings glut by a savings wedge as we do in this paper follows Kehoe, Ruhl, and Steinberg (2016).

for the 2010 steady states, to ensure that we match the observed drop in the U.S. net foreign asset position during this period.

There is only one type of capital and labor in the rest of the world and production takes place according to a standard Cobb-Douglass production function

$$F(K, L) = \hat{A} K^{\hat{\alpha}} L^{1-\hat{\alpha}}.$$

Agents in the rest of the world face idiosyncratic labor income risk, $\hat{z}$ where, like in the U.S. economy, the logarithm of $\hat{z}$ is the sum of two orthogonal components: a persistent autoregressive shock and a transitory shock. More precisely,

$$\log \hat{z}_t = \hat{\theta}_t + \hat{\varepsilon}_t,$$
$$\hat{\theta}_t = \hat{\xi} \hat{\theta}_{t-1} + \hat{\kappa}_t,$$

where $\hat{\varepsilon}_t$ and $\hat{\kappa}_t$ are drawn from distributions with mean zero and variances $\sigma_{\hat{\varepsilon}}$ and $\sigma_{\hat{\kappa}}$. $\hat{\xi}$ represents the persistence parameter of the AR(1) process that governs the persistent component.

Agents from the two countries (United States and the rest of the world) can engage in intertemporal bond trading with one another at the world interest rate R. Letting IIP and $I\hat{I}P$ denote the net international investment positions of the United States and rest of the world economies respectively, the market clearing for the bond world market is given by

$$IIP + I\hat{I}P = 0.$$

Finally, we assume there is no government in the rest of the world.

6.2 Calibration of the Two-Country Model

First, we calibrate the model economy to the 1967 world economy. Since we know the net international investment position of the two economies for 1967, we proceed by calibrating the two economies separately.

The procedure for calibrating the model to the 1967 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 of the United States to its observed value in 1967. The IIP is only reported in the National Income and Product Accounts (NIPA) from year 1976 onwards, when it was 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), IIP as a fraction of GDP did not change much in the decade before 1976. Therefore, we set IIP to 10% of GDP in 1967. This gives us a calibrated net world real interest rate of 1.13%.

The rest of the world economy corresponds to a single large economy that consists of the 20 largest trading partners of the United States as reported by the U.S. International Trade Administration. For the rest of the world, we set the preference parameters to their values in the U.S. economy: $\hat{\sigma} = \sigma$ and $\hat{\beta} = \beta\delta$. We choose the parameters of the wage process $\sigma_{\hat{\varepsilon}}$, $\sigma_{\hat{\kappa}}$, and $\hat{\xi}$ to the weighted average of the corresponding values for Germany, U.K., France, and Italy, as estimated by LeBlanc and Georgarakos (2013). We assume that these parameters do not change between the 1967 and 2010. We set $\hat{\alpha} = 1/3$.

We use the Angus Maddison historical data set to calculate the total population of the 20 countries that form the rest of the world economy. We find that the population of the rest of the world was 9.3 times the US population in 1967. Nor-

Table 7: Open Economy Parameterization

Parameter	Symbol	Value	Target	Value	Source
Exogenously set parameters					
R.O.W. risk aversion	$\hat{\sigma} = \sigma$	2			
R.O.W. discount factor	$\hat{\beta} = \beta\delta$	0.9803			
R.O.W. capital share	$\hat{\alpha}$	1/3			
R.O.W. variance of transitory shock	$\sigma_{\hat{\epsilon}}$	0.0399			LG
R.O.W. variance of persistent shock	$\sigma_{\hat{\kappa}}$	0.158			LG
R.O.W. persistence paramerter	$\hat{\xi}$	0.9335			LG
Calibration 1967					
World interest rate	R	1.13%	U.S. IIP/U.S. GDP	10%	Howard
R.O.W. savings wedge	$\hat{\psi}$	0.9474	R.O.W. IIP/U.S. GDP	-10%	Howard
R.O.W. TFP	$\hat{A}$	0.1910	R.O.W. GDP/U.S. GDP	1.76	Maddison
R.O.W. population		9.3	R.O.W. pop/U.S. pop	9.3	Maddison
Calibration 2010					
World interest rate	R	0.47%	U.S. IIP/U.S. GDP	-16.3%	NIPA
R.O.W. savings wedge	$\hat{\psi}$	0.9575	R.O.W. IIP/U.S. GDP	16.3%	NIPA
R.O.W. TFP	$\hat{A}$	0.3270	R.O.W. GDP/U.S. GDP	2.25	Maddison
R.O.W. population		11	R.O.W. pop/U.S. pop	11	Maddison

This table reports the parameters used in the open economy exercises. LG refers to LeBlanc and Georgarakos (2013).

malizing the population of the U.S. economy to 1, the population of the rest of the world is then set to 9.3. Finally, given these parameter values, we choose the saving wedge and the total factor productivity in the rest of the world to match (i) the rest of the world net international investment position in the 1967 (-10% of the U.S. GDP) and ii) the ratio of the rest of the world GDP to the U.S. GDP in 1967 which equals 1.76. We calculate the rest of the world data GDP by summing up the GDP's of the 20 economies as they are reported in the Angus Maddison data set.

Next, we recalibrate our model to the 2010 to ensure that it matches the international investment positions in the 2010. To do so, we first choose the world interest rate in 2010 to match the net international investment position of the United States in the same year, which is computed to be -16.3% of U.S. GDP. The resulting world interest rate is 0.47% (in line with the global decline in capital returns). We still need to calibrate the population, the total factor productivity and the saving wedge of the rest of the world economy to 2010. According to the Angus Maddison historical dataset, the population of the rest of the world defined as before is 11 times that of the US population in 2010. Keeping the normalization of the population of the US economy at 1, the population of the rest of the world is then set to 11. Given these parameter values, we choose the saving wedge and the TFP in the rest of the world to match (i) the rest-of-the-world net international investment position in the 2010 (16.3% of the U.S. GDP) and ii) the fraction of the rest of the world GDP to the U.S. GDP, which equals 2.25 in 2010 and is calculated exactly the same as it is calculated for 1967. The calibration procedure is summarized in Table 7.

The results of the open economy calibration exercises are reported in the third and fourth columns of Table 8. 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 1.51 to 1.88 in the open economy exercise which is almost identical to the change we observe in the benchmark closed economy exercise. One might find this surprising because, as the fourth row of Table 8 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 1967 and the 2010.

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 happens only to a very limited extent, however,

Table 8: Open Economy

	1967 closed	2010 closed	1967 open	2010 open
IIP/GDP	0%	0%	10%	-17.5%
Skill premium	1.51	1.87	1.51	1.88
Total capital	0.82	2.18	0.82	2.23
Domestic assets	0.82	2.18	0.84	2.12
Foreign assets	0	0	-0.03	0.11
After tax return	1.13%	0.55%	1.13%	0.47%

for two reasons. First, the inflow of foreign assets is relatively small compared to the size of the U.S. capital stock (0.14 vs. 2.12). Second, as the third row of the Table 8 shows, domestic savings in the open economy in 2010 are smaller than domestic savings in the closed economy, because the interest rate is smaller in the open economy (consistently with the capital inflow). In a sense, foreign savings crowd out domestic savings and thereby do not increase capital accumulation and hence the skill premium too much. Thus, we conclude that whether one interprets the U.S. as a closed or a large open economy does not change model's prediction regarding the overall rise in skill premium much.[6]

6.3 Quantitative Implications of the Rise in U.S. Wage Risk and the "Savings Glut"

The second question we want to answer is whether the rise in individual wage risk is still an important factor in causing the rise of the skill premium between 1967 and 2010 when we model the U.S. as an open economy. The third column of Table 9 reports that the rise in wage risk still contributes substantially to the rise in skill

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

Table 9: Open Economy Decomposition

	1967	2010	Risk	Risk + Savings Glut
Skill premium	1.51	1.88	1.59	1.65
Contribution			19%	36%
Total capital	0.82	2.23	0.94	1.07

premium: if we only allow for risk to change keeping all the other factors in the United States and the rest of the world constant, the skill premium in the United States would still go up by 9 percentage points, or by 19% of the total change in skill premium observed during this period. Notice from the last row of the table that, as expected, the rise in wage risk increases skill premium by increasing capital accumulation.

Finally, we also analyze the effect of the rise in rest-of-the-world investment in the U.S. economy on U.S. skill premium by changing the rest of the world economy's total factor productivity, population size and the saving wedge to their 2010 values in addition to the change in risk and looking at the differential increase in the skill premium. The last column of Table 9 shows that the change in the rest of the world increases skill premium by additional 6 percentage points which accounts for about 17% of the total change in skill premium.

7 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. (2014): "Skills, education, and the rise of earnings inequality among the "other 99 percent"," *Science*, 344(6186), 843–851.

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.

BERNANKE, B. S. (2005): "The global saving glut and the U.S. current account deficit," Discussion 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.

DICECIO, R. (2009): "Sticky wages and sectoral labor comovement," *Journal of Economic Dynamics and Control*, 33(3), 538–553.

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.

HONG, J. H., B. H. SEOK, AND H. M. YOU (2015): “Wage Volatility and Changing Patterns of Labor Supply,” Discussion paper, working paper.

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,".

KEHOE, T. J., K. J. RUHL, AND J. STEINBERG (2016): "Global imbalances and structural change in the United States," Discussion paper.

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.

LEBLANC, J., AND D. GEORGARAKOS (2013): "How Risky is their Income? Labor Income Processes in Europe," Working paper.

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.

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

YAARI, M. E. (1965): "Uncertain Lifetime, Life Insurance, and the Theory of the Consumer," *The Review of Economic Studies*, 32(2), 137–150.