Wage Risk and the Skill Premium

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The skill premium has increased significantly in the United States in the last five decades. During the same period, individual wage risk has also increased. This paper proposes a mechanism through which a rise in wage risk increases the skill premium. Intuitively, a rise in uninsured wage risk increases precautionary savings, thereby boosting capital accumulation, which increases the skill premium due to capital-skill complementarity. Using a quantitative macroeconomic model, we find that the rise in wage risk observed between 1967 and 2010 increases the skill premium significantly. This finding is robust across a variety of model specifications.

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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 the United States in recent decades. Another important finding that has been documented by Gottschalk and Moffitt (1994), Heathcote, Storesletten, and Violante (2010), Gottschalk and Moffitt (2012) and Hong, Seok, and You (2017), among others, is that U.S. workers face a considerably higher level of individual wage risk now than in the past. This paper uncovers a link between the rise in individual wage risk and the rise in the skill premium. In particular, we propose a mechanism through which a rise in individual wage risk leads to an increase in the skill premium and shows that this mechanism can be quantitatively significant.

The proposed mechanism is straightforward and rests on two notions with long-standing traditions in economics. The first is the precautionary savings motive, which is the idea that an increase in (uninsured) income risk induces people to save more.[1] The second is capital-skill complementarity: the idea that capital is relatively more complementary with skilled labor than it is with unskilled labor.[2] Intuitively, in a world in which insurance markets are imperfect, a rise in individual income risk increases aggregate savings through the precautionary savings motive, which boosts capital accumulation. The rise in the capital stock then increases the skill premium due to capital-skill complementarity.

We lay this mechanism out using a model that embeds capital-skill complementarity into an incomplete markets model a là Aiyagari (1994), which has been a workhorse model for studying the effects of precautionary savings on the macroeconomy. The precautionary savings motive is present in this model because individuals face uninsured idiosyncratic wage risk. Capital-skill complementarity is built in by assuming a production function

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[1]Kimball (1990), Deaton (1991) and Carroll (1994) provide seminal early contributions to the study of precautionary savings.

[2]Griliches (1969) was the first to formalize and test the capital-skill complementarity hypothesis. Since then, it has received much attention from economists. Among others, see Fallon and Layard (1975), Krusell, Ohanian, Ríos-Rull, and Violante (2000), Flug and Hercowitz (2000), and Duffy, Papageorgiou, and Perez-Sebastian (2004).

that 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). We use this model to evaluate the quantitative significance of our mechanism for the U.S. economy by calculating the extent to which the rise in individual wage risk contributed to the rise in the skill premium between 1967 and 2010.

We solve for the stationary competitive equilibrium of this model and calibrate the model parameters to match the 1967 U.S. economy along certain dimensions including the level of the skill premium. Then, we introduce the changes in the structure of individual wage risk observed between 1967 and 2010, as estimated by Hong, Seok, and You (2017), as well as the changes in two key factors that have found significant support in the literature in terms of determining the changes in the skill premium. These factors are technological advancements that favor skilled workers (skill-biased technical change) and the rise in the relative supply of skilled workers.[3] Following Krusell, Ohanian, Ríos-Rull, and Violante (2000), skill-biased technical change is modelled as a decline in the price of equipment. Having introduced changes in the structure of wage risk, technology, and relative supply of skilled workers, we solve for the new steady state, which corresponds to 2010. The model generates a 41 percentage point increase in the skill premium, from 1.51 in 1967 to 1.92 in 2010. In the data, the U.S. skill premium increases by 39 percentage points to 1.90 in 2010.[4] We conclude that the model provides a reliable laboratory to investigate the sources of changes in the U.S. skill premium.

Next, we investigate the quantitative significance of our mechanism by calculating how much the rise in wage risk contributed to the rise in the skill premium during the period of interest. To do so, we compute a counterfactual steady state in which the structure of wage risk is as it was in 2010, but all other factors are at their 1967 levels. We find that the rise in wage risk alone increases the skill premium to 1.70, an increase of 18 percentage

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[3]The notion that relative wages of college vs. non-college graduates are determined as a result of a 'race' between technology and education is originally due to Tinbergen (1974). See also Acemoglu and Autor (2011) for a survey of the literature.

[4]Heathcote, Perri, and Violante (2010) calculate the skill premium for the 1967-2005 period. We follow their methodology and extend the skill premium series to 2010.

points relative to the 1967 steady state. In an alternative exercise, we feed in the changes in technology and the supply of skilled agents that occurred between 1967 and 2010, but keep the structure of wage risk as in the 1967 economy. In this counterfactual exercise, the U.S. skill premium equals 1.80, which is 12 percentage points shy of the model implied skill premium for 2010.[5] A comparison of these numbers to the observed 39 (or the model implied 41) percentage point change in the skill premium suggests that the rise in wage risk has a quantitatively significant effect on the skill premium. This conclusion is further supported by sensitivity analyses with respect to individuals' degree of risk aversion and the tightness of borrowing constraints.

In the baseline model, the United States is modelled as a closed economy and the supply of skilled agents is exogenous. Section 7 provides an extension in which the United States is treated as a large open economy. We find that modelling the United States as a large open economy does not affect the model's success in generating the overall rise in the U.S. skill premium. More importantly, the rise in the U.S. wage risk still contributes significantly to the rise in the U.S. skill premium. Section 8 analyzes a separate extension which shows that the effect of the rise in wage risk on the skill premium remains significant when education decisions (and hence the supply of skilled workers) are endogenous.

In our model, the rise in wage risk between 1967 and 2010 increases aggregate savings through the precautionary savings channel. At a first glance, this may seem to be in contrast with the fact that the U.S. national savings rate declined over the same period. This conclusion is not necessarily correct, however. Arguably, the main reason for the decline in the U.S. savings rate during this period is the rise in capital inflows from abroad and the resulting decline in interest rates. If we modelled this rise in capital inflows between 1967 and 2010 taking into account transitional dynamics, our model could replicate the decline in the savings rate even in the presence of the rise in precautionary savings. The fact that we do not match the decline in U.S. savings does not mean that the rise in wage risk has been quantitatively unimportant for aggregate savings.

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[5]The fact that the two counterfactuals attribute different magnitudes to the importance of wage risk (18 vs. 12 percentage points) alludes to the significant non-linearities present in the model.

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We would also like to stress that this paper does not aim to propose a competing theory of what determines changes in the skill premium. To the contrary, our model confirms the findings in the existing literature that skill-biased technical change and changes in the supply of skilled workers have been the most important determinants of changes in the skill premium. Our analysis merely puts forth the idea that changes in wage risk can have a quantitatively significant effect on the skill premium.

Related Literature. This paper relates to a large literature that aims to explain the rise of the skill premium in the United States in recent decades. Goldin and Katz (2008) is a monumental work analyzing the evolution of the U.S. wage structure in general and the skill premium in particular through the lens of Tinbergen's (1974) model of the race between education and technology. 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 along with the observed changes in inputs to explain the evolution of the skill premium between 1965 and 1992. Buera, Kaboski, and Rogerson (2015) analyze the role of structural change on the skill premium between 1977 and 2005. The authors find that structural change has also been skill-biased and has contributed significantly to the rise of the skill premium during this period. Burstein and Vogel (forthcoming) build a Ricardian model of international trade in which there are skill intensity differences across firms and sectors and skill abundance differences across countries. Using this model, the authors show that reductions in trade costs can generate significant increases in the skill premium in almost all 60 countries in their sample.[6] We add to this literature by uncovering a novel factor that has contributed to the observed rise in the skill premium; the increase in wage risk.

Ex-ante idiosyncratic wage risk implies ex-post within-group inequality in our model. In this sense, one possible interpretation of this paper is that it proposes a mechanism that links within-group inequality and between-group inequality (the skill premium). Gu-

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[6]Other contributions to the study of the determinants of the skill premium include Hornstein and Krusell (1996), Greenwood and Yorukoglu (1997), Galor and Tsiddon (1997), Heckman, Lochner, and Taber (1998), Caselli (1999), Violante (2002), Domeij and Ljungqvist (2006), He and Liu (2008), Guvenen and Kuruscu (2010) and Burstein, Morales, and Vogel (2015), among others. See also Larrain (2015) for a contribution related to the open economy extension analyzed in this paper.

venen and Kuruscu (2012) build a model of the labor market where, for all workers, both skilled and unskilled, labor consists of two parts: raw labor and human capital. Using this model, the authors show that (exogenous) skill-biased technical change can explain the evolution of both within-group and between-group inequalities. Acemoglu (1998) proposes a directed technical change model in which an increase in the relative supply of the skilled workers encourages firms to develop technologies that are more complementary to these workers, creating an endogenous skill bias in technological progress. In an extension of this model, the author shows that his framework has the potential to explain the joint evolution of the between- and within-group inequalities.

This paper is also related to a large incomplete markets literature in the Bewley (1986), Imrohoroglu (1989), Huggett (1993) and Aiyagari (1994) tradition. The two papers that are most closely related to ours in this literature are Heathcote, Storesletten, and Violante (2010) and Hong, Seok, and You (2017). Heathcote, Storesletten, and Violante (2010) estimate the changes in wage risk over time and analyze the macroeconomic implications of the rise in wage risk, also taking into account changes in the skill premium and the gender gap. Hong, Seok, and You (2017) estimate changes in wage risk separately for the skilled and unskilled and analyze the implications of the rise in wage risk for the labor supply of skilled and unskilled workers.[7]

The rest of this paper is structured as follows. Section 2 describes the model in detail while Section 3 briefly discusses the mechanism and provides a layout of its quantitative assessment. Section 4 explains how the model is calibrated to the 1967 U.S. economy. Section 5 summarizes the changes in skill premium, wage risk and other factors between 1967 and 2010. Section 6 discusses our main quantitative findings. In Sections 7 and 8, we consider two extensions to the basic framework: An open economy extension with international trade in goods and capital, and an extension to the basic framework in which people's skill supply is endogenous. Section 9 concludes. The Appendix contains the details of our empirical calculations.

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[7]The finding that wage risk has increased in the United States in the last few decades has been challenged by a few recent studies, most notably Sabelhaus and Song (2010), who use large administrative data sets. See also the discussion titled '*Trends in volatility: a brief digression.*' on page 631 of Guvenen, Ozkan, and Song (2014).

2 Model

This section develops an infinite horizon closed economy growth model with two types of capital (structure and equipment capital), 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. The assets of deceased people are distributed among the survivors proportional to the survivors' wealth. This assumption is equivalent to assuming that people can buy actuarially fair life insurance policy. Life before labor market entry is not modelled.

Skill Heterogeneity and Wage Risk. 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 masses of skilled and unskilled agents are denoted by π_s and π_u, respectively. In the quantitative analysis, skill types correspond to educational attainment at the time of labor market entry. Agents with college education or above are classified as skilled agents and the rest of the agents are classified as unskilled agents. Section 5 describes the increase in the relative supply of skilled workers, π_s, observed between 1967 and 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. The productivity shock z_i denotes how many units of effective labor per unit of time an agent is able to provide. As a result, an agent's wage rate per unit of time is $w_i \cdot z_i$, where w_i is the marginal product of effective labor of skill type i. The stochastic processes that govern this wage risk are allowed to be different for the two skill groups. The logarithm of z_i is modelled as a sum of two orthogonal components: a persistent autoregressive shock

and a transitory shock. More precisely,

$$\log z_{i,t} = \theta_{i,t} + \varepsilon_{i,t}, \tag{1}$$

$$\theta_{i,t} = \xi_i \theta_{i,t-1} + \kappa_{i,t}, \tag{2}$$

where $\varepsilon_{i,t}$ and $\kappa_{i,t}$ are independently and identically distributed across agents and over time according to a normal distribution with mean zero and variances $\sigma_{i,\varepsilon}$ and $\sigma_{i,\kappa}$. ξ_i controls the degree of persistence of the persistent component. Agents draw the initial value of the persistent component of their labor productivity at age $h = 0$ from a normal distribution with mean zero and variance $\sigma_{i,\theta}$. For notational simplicity, we define the vector of idiosyncratic productivity components by $\mathbf{z_i} = (\theta_i, \varepsilon_i) \in \mathcal{Z}_i$.

The change in idiosyncratic wage risk is modelled by allowing the variances $\sigma_{i,\varepsilon}$ and $\sigma_{i,\kappa}$ to change over time. Section 5 discusses the observed changes in these variances between 1967 and 2010. We normalize the mean levels of the idiosyncratic labor productivity shocks to one, i.e., set $E[z_i] = 1$ in both 1967 and 2010 for both skill types. This normalization ensures that changes in the stochastic processes for z_is over time are purely changes in risk. As a result, the skill premium in the model economy is given by the ratio of the marginal products of (effective) labor w_s/w_u.

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 $\beta \in (0, 1)$ 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 process governing the idiosyncratic wage risk for an agent of skill type i. There are no aggregate shocks. Modelling elastic labor supply is especially important since this margin gives agents an additional tool to insure themselves against income shocks.

Technology. There is a constant returns to scale production function: $Y = F(K_s, K_e, L_s, L_u)$,

in which 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. δ_s and δ_e denote the depreciation rates of structure and equipment capital, respectively.

The key feature of the technology 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 in turn 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 consistent with the estimation results of Krusell, Ohanian, Ríos-Rull, and Violante (2000).

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

Finally, at time t, one unit of the general consumption good can be converted into one unit of structure or into $\frac{1}{q_t}$ units of equipment capital. This means that the relative prices of structure and equipment capital in terms of the general consumption good are 1 and q_t, respectively. Following the literature, we model skill-biased technical change as a decline in q over time. Section 5 discusses the observed change in q between 1967 and 2010.

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, the maximization problem of the firm 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

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$w_{s,t}$ are wage rates paid to unskilled and skilled effective labor in period t.

Government. The government applies linear taxes to 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 makes it possible to model the progressivity of the U.S. labor income tax code, which is important because progressive taxes provide (partial) insurance against wage risk. The government uses taxes to finance a stream of expenditures $\{G_t\}_{t=0}^{\infty}$ and to repay government debt $\{D_t\}_{t=0}^{\infty}$.

Asset Market Structure. Government debt is the only financial asset. It has a one period maturity and return R_t. Consumers can also save through the two types of capital. In the absence of aggregate shocks, the returns to savings in the form of the two capital types are certain, as is the return on government bonds. Therefore, all three assets must yield the same after-tax return in equilibrium, i.e., $R_t = 1 + (r_{s,t} - \delta_s)(1 - \tau_{s,t}) = \frac{q_t + (r_{e,t} - q_t \cdot \delta_e)(1 - \tau_{e,t})}{q_t}$. As a result, one does not need to distinguish between savings via different types of assets in the consumer's problem. Consumers' (total) asset holdings will be denoted by a and $\mathcal{A} = [0, \infty)$ denotes the set of possible asset levels that agents can hold. Section 6.6 analyzes an extension in which agents are allowed to borrow. Our assumptions imply that, in every period, the total savings of consumers must be equal to the total borrowing of the government plus the total capital stock in the economy.

Our quantitative analysis focuses on the comparison of stationary equilibria where one stationary equilibrium corresponds to 1967 and another one to 2010. For that reason, instead of giving a general definition of competitive equilibrium, we only define stationary recursive competitive equilibria. In order to define a stationary equilibrium, government policies (expenditure, debt and taxes) are assumed not to change over time.

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 $\tau_s, \tau_e, T(\cdot), D, G$, 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 $i \in \{u, s\}$:

$$V_i(\mathbf{z_i}, a_i) = \max_{\{c_i, l_i, a'_i\}} \quad u(c_i, l_i) + \beta \delta E_i[V_i(\mathbf{z'_i}, a'_i)] \qquad \text{s.t.}$$

$$c_i + \delta a'_i \leq w_i z_i l_i - T(w_i z_i l_i) + R a_i,$$

$$c_i \geq 0, \quad l_i \in [0, 1], \quad a'_i \in \mathcal{A},$$

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

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

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 the 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. The government budget constraint is satisfied:

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

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 The Mechanism and its Quantitative Assessment

The main purpose of this paper is to propose a mechanism through which a rise in individual wage risk leads to an increase in the skill premium. This section first discusses how this mechanism works in the model laid out in Section 2. Second, we describe how the mechanism is evaluated quantitatively in the rest of the paper.

In the model outlined in Section 2, a rise in wage risk increases people's (precautionary) savings because insurance markets are incomplete. The resulting increase in aggregate savings implies a corresponding increase in aggregate capital stock, which implies an increase in the levels of equipment and structure capital. Recall that, by construction, productivity shocks are mean one in the model. As a result, the skill premium, which is defined as the average wage rate of the skilled, divided by the average wage rate of the unskilled, equals w_s/w_u, which satisfies

$$
\frac{w_s}{w_u} = \frac{F_3(K_s, K_e, L_s, L_u)}{F_4(K_s, K_e, L_s, L_u)}. \tag{3}
$$

The assumption of equipment-skill complementarity means that the ratio on the right-

hand side of equation (3) is increasing in the level of equipment capital. Under the assumption that structure capital is neutral, this implies that the skill premium is increasing in aggregate capital stock.

In order to evaluate this mechanism quantitatively, we first solve for the stationary equilibrium of the model defined in the previous section and calibrate it to the 1967 U.S. economy. In this computation, the level of individual wage risk and the other relevant factors, technology and the relative supply of skilled workers, are set to their 1967 values. Then, we solve for another stationary equilibrium in which the level of individual wage risk and the other factors are set to their 2010 levels, while the rest of the parameters are kept fixed at their calibrated values. The fit of the model is then assessed by comparing the change in the skill premium between 1967 and 2010 steady states to the corresponding change in the data.

We then turn to our main quantitative exercise of interest. We compute a counterfactual steady state in which the individual wage risk is set to its 2010 level while the rest of the factors are kept at their 1967 levels. A comparison of the skill premium between this steady state and the 1967 steady state provides a measure of the effect of the rise in wage risk on the skill premium.

4 Calibrating the Model to 1967

One period in the model corresponds to one year. The structural parameters of the model are set assuming that the SRCE of our model economy under the 1967 technology, relative supply of skilled workers, residual wage risk, and government policies coincides with the U.S. economy of 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, from the Panel Study of Income Dynamics (PSID), are from 1967. For

data availability reasons, we focus on working age males, when we compare the model with data. This concerns the skill premium and educational attainment as well as the idiosyncratic productivity processes. The details of our data work are included in the Appendix.

Technology. The production function takes the same form as in Krusell, Ohanian, Ríos-Rull, and Violante (2000):

$$Y = F(K_s, K_e, L_s, L_u) = K_s^\alpha \left(\nu \left[\omega K_e^\rho + (1-\omega) L_s^\rho \right]^{\frac{\eta}{\rho}} + (1-\nu) L_u^\eta \right)^{\frac{1-\alpha}{\eta}}. \tag{4}$$

In this formula, 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. The parameter α gives the income share of structure capital. Krusell, Ohanian, Ríos-Rull, and Violante (2000) estimate α, ρ, η, and we use their estimates. Their estimates of ρ and η imply that equipment capital is more complementary with skilled than unskilled labor. The other two parameters in this production function, ν and ω, jointly control the income shares of equipment capital, skilled labor and unskilled labor. These parameters are calibrated internally, as explained in detail later. The price of equipment capital is normalized to one, $q = 1$, for the benchmark 1967 calibration.

Preferences and Demography. 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 the Frisch elasticity of labor supply. In the benchmark case, we use $\sigma = 2$ and calibrate ϕ to match the average labor supply. The resulting Frisch elasticity of labor supply is 1.16 for an agent with the average labor supply in the economy.[8] This value is within the range of labor supply elasticities used in

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[8]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 $\frac{1-l}{l} \frac{\sigma}{1-\frac{1-\sigma}{\phi}}$.

the macro literature. Agents in the model are born at the real life age of 25 and enter the labor market immediately. Following Castaneda, Díaz-Giménez, and Ríos-Rull (2003), the survival probability δ is set to 0.978 to match the average working life-span of 40 years. The discount rate β is calibrated internally as discussed below.

The fraction of skilled agents in 1967, π_s^{67}, is 0.1356 in the Current Population Survey (CPS) data. This number is calculated using educational attainment for males of 25 and older who have earnings. To be consistent with Krusell, Ohanian, Ríos-Rull, and Violante (2000), skilled people are defined as those who have at least 16 years of schooling (college degree of 4 years).

Wage Risk. Recall that skilled and unskilled agents (indexed by i) are assumed to face different stochastic processes for labor productivity shocks modelled as the sum of a persistent autoregressive component and a transitory component as given by equations $(1)-(2)$. Hong, Seok, and You (2017) use the Panel Study of Income Dynamics data from 1967 to 2010 and estimate the parameters of these processes for each skill group separately. Following Heathcote, Storesletten, and Violante (2010), they assume that the persistence parameters ξ_i and the variances of the initial draws of the persistent components $\sigma_{i,\theta}$ are constant over time. The variances of the shocks of the persistent components $\sigma_{i,\kappa}$ and the variance of the shocks of the transitory components $\sigma_{i,\varepsilon}$ are assumed to change over time and Hong, Seok, and You (2017) estimate them for all years in the PSID sample.[9] The estimated variances are very volatile across years. For that reason, for each (variance) parameter, we take the average of the estimated values for the five years between 1967 and 1971 and set the parameter value for the 1967 steady state equal to this average. The variances of the initial distributions of the persistent component for both skill groups, $\sigma_{i,\theta}$, and the persistence parameters ξ_i are also taken from Hong, Seok, and You (2017). All parameter values regarding the idiosyncratic wage risk are reported in the 'Residual Wage Risk' panel of Table 1. Numerically, these processes are approximated by finite number Markov chains using the Rouwenhorst method described in Kopecky and Suen

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[9]We use the estimates of Hong, Seok, and You (2017) rather than Heathcote, Storesletten, and Violante (2010) because the former estimate the productivity processes separately for skilled and unskilled individuals and provide the estimates up to 2010.

(2010).

Government. The government consumption-to-output ratio is set to 16%, which approximately equals the average ratio in the United States during the period 1970-2012, as reported in the National Income and Product Accounts (NIPA) data.

As for labor income taxes, modelling the progressivity of the U.S. 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. A higher degree of progressivity can decrease the after-tax income risk agents face and thereby decrease the need for precautionary savings. To approximate the progressive U.S. labor tax code, we follow Heathcote, Storesletten, and Violante (2017) 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 2000-2006, Heathcote, Storesletten, and Violante (2017) estimate $\tau_l = 0.181$.[10] We use their estimate and, as in their paper, set χ to clear the government budget in steady state.

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 1960s, the average tax rate on equipment capital was approximately 41%, while the average tax on structures was approximately 49% at the firm level.[11] 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

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[10]Importantly, the tax liability measure of Heathcote, Storesletten, and Violante (2017) takes into account public cash transfers (AFDC/TANF, SSI and other welfare receipts, unemployment benefits, workers' compensation, and veterans' pensions). As a result, taxes at the bottom of the income distribution are in fact negative, providing insurance against the risk of low income.

[11]The annual tax rate estimates of Auerbach (1983) are very volatile due to changing inflation rates across years. For this reason, we use the averages over the 1960s instead of the point estimates for 1967 to represent the tax rates at the initial steady state.

Table 1: Benchmark Parameters for 1967

Parameter	Symbol	Value	Source
Preferences			
Relative risk aversion parameter	σ	2	
Probability of death	δ	0.022	
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
Residual 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	0.181	HSV (2017)
Overall structure capital tax in 1967	τ_s	0.5665	Auerbach (1983)
Overall equipment capital tax in 1967	τ_e	0.4985	Auerbach (1983)
Government consumption	G/Y	0.16	NIPA
Government debt in 1967	D/Y	0.25	St. Louis FED

This table reports the benchmark parameters taken directly from the literature or the data. The acronyms GHK, HSV, HSY, and KORV stand for Greenwood, Hercowitz, and Krusell (1997), Heathcote, Storesletten, and Violante (2017), Hong, Seok, and You (2017), and Krusell, Ohanian, Ríos-Rull, and Violante (2000), respectively. CPS and NIPA stand for Current Population Survey and National Income and Product Accounts, respectively.

Table 2: Internally Calibrated Parameters for 1967

Parameter	Symbol	Value	Target	Data & SRCE	Source
Production parameter	ω	0.7886	Labor share	0.67	NIPA
Production parameter	ν	0.4530	Skill premium in 1967	51%	CPS
Disutility of labor	ϕ	0.4088	Labor supply	1/3	
Discount factor	β	0.9907	Capital-to-output ratio	2	NIPA, FAT
Tax function parameter	χ	0.8778	Gvt. budget balance		

This table reports the benchmark calibration procedure. The production function parameters ν and ω jointly control the share of equipment capital, skilled labor and unskilled labor in total output. The tax function parameter χ controls the labor income tax rate of the mean income agent. CPS, FAT and NIPA stand for Current Population Survey, Fixed Asset Tables and National Income and Product Accounts, respectively.

$\tau_e = 1 - 0.85 \cdot (1 - 0.41) = 49.85\%$. Finally, we set the government debt-to-GDP ratio to 25% for 1967 as reported by the Federal Reserve Bank of St. Louis Database. This number corresponds to U.S. federal government debt held by the domestic private sector and, hence, does not include U.S. federal government debt held by other government agencies. Because the benchmark model economy is a closed economy, federal debt held by foreign and international investors is also excluded when computing the government debt-to-GDP ratio.

Internal Calibration. There are still five parameter values that are left to be determined: the two production function parameters, ω and ν, which (given the income share of structure capital) jointly 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 to ensure that the model matches the 1967 U.S. economy regarding the following two moments: the first moment is the share of labor income in total income. The labor share is computed from NIPA using the methodology described in Ríos-Rull and Santaeulàlia-Llopis (2010). The second moment is the skill premium in 1967, which is reported to be 1.51 by Heathcote, Perri, and Violante (2010) for males aged 25-60 with at least 260 working hours per year in the CPS.

The preference parameter ϕ is set so that the aggregate labor supply in steady state equals 1/3 as commonly assumed in the literature. The discount rate β is calibrated to match the U.S. capital-to-output ratio, which is calculated using the NIPA and Fixed

Asset Tables. Housing is excluded from both capital stock and output calculation to be consistent with Krusell, Ohanian, Ríos-Rull, and Violante (2000) whose elasticity estimates we use. The resulting annual capital-output ratios vary between 1.8 and 2.4 during 1967-2010, mostly due to short-term fluctuations in output. To abstract away from these fluctuations, we take the average of annual capital-output ratios over this period, which gives a capital-to-output ratio of 2 for the U.S. economy. Finally, χ is chosen to clear the government budget constraint in equilibrium. Table 2 summarizes the internal calibration procedure.

5 Changes in the Skill Premium, Wage Risk, and Other Factors Between 1967 and 2010

This section summarizes the changes in residual wage risk and the skill premium observed in the U.S. economy between 1967 and 2010. Then it describes the changes in other factors that are important for the skill premium: the skill-biased technical change and the relative supply of skilled workers. We also describe changes in government policies that may have had a quantitatively significant effect on the skill premium.

5.1 Changes in Wage Risk and the Skill Premium

The skill premium in the United States rose by a significant margin between 1967 and 2010. Heathcote, Perri, and Violante (2010) use CPS data to compute the skill premium for 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 the U.S. skill premium to 2010. Our calculations show that the skill premium was approximately constant throughout 2005 - 2010 period and was equal to 1.9 in 2010. This is in line with Autor (2014) who also finds that the skill premium has flattened out between 2005 and 2010.

During the same time period, the U.S. economy also experienced a significant increase in residual wage risk. Table 3 below reports the rise in the estimates of the variances of both persistent and transitory shocks provided by Hong, Seok, and You (2017) between

Table 3: Changes in Wage Risk Between 1967 and 2010

Parameter	1967	2010
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

This table reports the variances of the transitory and persistent components of the stochastic wage processes for 1967 and 2010. The values reported in this table are from Hong, Seok, and You (2017).

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). 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 assumed to be constant over time.

5.2 Changes in Other Factors

This section describes in detail the changes in factors other than risk that are expected to have affected the skill premium between 1967 and 2010. These factors are technology, the relative supply of skilled workers and government policy.

Technology. Our measure of technological improvement (skill-biased technical change) is the change in the relative price of equipment capital, q. Following the methodology of Cummins and Violante (2002), DiCecio (2009) documents that the price of equipment capital in consumption good units decreased from the normalized value of 1 in 1967 to 0.1577 in 2010 (this number comes from an update of DiCecio's work available in the St. Louis FED Database). 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 calculations provided by both Cummins and Violante (2002) and DiCecio

(2009), the price of structure capital relative to consumption 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 use to compute it for 1967. As before, we consider only 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 equipment at the corporate level were 32% and 26% in 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 2010 while in 1967 the numbers were substantially larger; 56.7% and 49.9%. Using the St. Louis Fed macroeconomic database, we compute that the U.S. government debt held by the domestic private sector relative to GDP increased from 0.25 in 1967 to 0.32 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 did not change 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.[12]

6 Quantitative Results

The main purpose of this section is to evaluate the quantitative implications of the rise in residual wage risk for the skill premium using our model. Before doing that, Section 6.1 analyzes to what extent the model can account for the change in the skill premium

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[12]Kaymak and Poschke (2015) try to overcome the issue, and estimate that $\tau_l = 0.08$ in 1967 and $\tau_l = 0.17$ in 2010. We conducted an exercise in which we changed the labor tax progressivity over time using their estimates and found that this does not have a significant effect on our main quantitative results.

Table 4: Change in the Skill Premium Between 1967 and 2010

	Data			Model		
	1967	2010	Change	1967	2010	Change
Skill premium	1.51	1.90	0.39	1.51	1.92	0.41

The first two columns in this table report the U.S. skill premium in 1967 and 2010. The skill premium data are computed using CPS data for males between ages of 25 to 60 who work at least 260 hours a year. The third column reports the change between 1967 and 2010. The next two columns report the model generated skill premia for the 1967 and 2010 steady states. The last column reports the change in the model generated skill premium between 1967 and 2010.

between 1967 and 2010. Then, Section 6.2 conducts two counterfactual exercises to measure the contribution of the rise in wage risk to the rise in the skill premium between 1967 and 2010.

6.1 Model Fit

To assess the model's fit regarding the skill premium, we first solve for a stationary equilibrium of the model which corresponds to 1967. We then solve for the 2010 stationary equilibrium of the model in which technology, the relative supply of skilled workers, wage risk, and government policy are set to their 2010 values.

Table 4 summarizes the model's success in explaining the observed changes in the skill premium in the United States between 1967 and 2010. The model generates the exact value of the skill premium in 1967. This is not surprising as the value of the skill premium in 1967 is a target in the calibration procedure. Comparing the second and the fifth columns of the table, we observe that the model performs well in terms of replicating the level of the skill premium in 2010: the model-generated skill premium level exceeds the actual level of the skill premium in 2010 by only two percentage points. Restated in terms of changes, the model replicates the rise in the skill premium well: 39 percentage points in the data vs. 41 percentage points in the model.

Before proceeding to the next section which investigates the quantitative significance of the rise in wage risk for the skill premium, we check whether the model generates reasonable changes in several key economic variables. Output grows by a factor of 2.3 in the model between the 1967 and the 2010 steady states, which is a fairly accurate

description of the growth experience of the U.S. economy during this period: according to the Federal Reserve Bank of St. Louis database (series A939RX0Q048SBEA), real output per capita grew by a factor of 2.2 between 1967 and 2010. Qualitatively, the model also captures the long-term decline in real interest rates observed in recent decades: in the model, the annual real return on government bonds decreases from about 3.3% to 2.4% between 1967 and 2010.[13] In the model, by assumption, all savings is done at the household level. For that reason, to compare savings in the model and in the data, it makes more sense to use the national savings rate rather than the household savings rate. The net national savings rate in the data declined between 1967 and 2010 whereas it stays constant in the model at 0%. This is because in both steady states investment simply replaces depreciated capital.

6.2   Quantitative Significance of the Changes in Wage Risk

Having checked the success of the model in replicating the observed rise in the skill premium between 1967 and 2010, we now use the model to perform two counterfactual exercises that allow us to quantify the effect of rising wage risk on the skill premium.

First, we compute a steady-state equilibrium of the model economy in which the wage risk parameters are set to their 2010 values but all other factors remain at their 1967 values. This counterfactual exercise is called "Only Risk". A comparison of the skill premium of this economy with the skill premium in 1967 reveals how much the change in wage risk increases the skill premium. As an alternative, we feed in the observed changes in all other factors keeping the structure of wage risk as it was in 1967. This counterfactual exercise is called "All but Risk". A comparison of the skill premium in this economy with the skill premium in 2010 measures how short the model falls of explaining the changes in the skill premium when the change in wage risk is omitted.

Table 5 shows that the increase in wage risk has a quantitatively significant effect

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[13]The labor share in the model remains roughly constant between 1967 and 2010. This is in contrast to recent empirical work which argues that labor share has declined in the last few decades; see, for instance, Karabarbounis and Neiman (2014). The fact that the production function we use does not capture the recent decline in the labor share is known from Krusell, Ohanian, Ríos-Rull, and Violante (2000).

Table 5: Model Implied Effects of Changes in Wage Risk on the Skill Premium

	1967	2010	Only Risk	All but Risk
Skill premium	1.51	1.92	1.70	1.80
Change			0.18	0.12

The first two columns of this table report the skill premia in the 1967 and the 2010 steady states in the model. The column 'Only Risk' reports the skill premium in the counterfactual exercise in which wage risk parameters are set to their 2010 values but all other factors remain at their 1967 values. The column 'All but Risk' reports the skill premium in the exercise in which wage risk parameters are set to their 1967 values, while the parameters that control all other factors are at their 2010 values. The second row of the 'Only Risk' column reports the change in the skill premium in the 'Only Risk' exercise relative to 1967 economy. The second row of 'All but Risk' column reports the difference between the skill premium values in the 2010 economy and 'All but Risk' exercise. Numbers may not add up due to rounding.

on the skill premium. Depending on the counterfactual analysis, the rise in wage risk generates 18 or 12 percentage points increase in the skill premium. This amounts to 44% or 30% of the total 41 percentage points rise in the skill premium between 1967 and 2010 that the model predicts. The change in wage risk affects the skill premium through the following mechanism. An increase in residual wage risk leads to higher precautionary savings.[14] Higher savings then lead 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. We verify this mechanism by computing the change in the stock of equipment capital that occurs due to the rise in wage risk. In the "Only Risk" exercise, equipment capital stock increases by about 20%. In the "All but Risk" exercise, the level of equipment capital is about 17% lower than in the exercise in which all factors, including risk, change to their 2010 levels.

The significance of our mechanism hinges upon the fact that (precautionary) savings respond strongly to changes in wage risk. The strong precautionary savings response in our model is consistent with Pijoan-Mas (2006) who shows that in a similar incomplete markets model calibrated to the U.S. economy precautionary savings are quantitatively important.

Insurance. The rise in wage risk increases the skill premium through the precautionary saving channel to the extent that wage risk is uninsured. In this sense, it is important

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[14]This rise in savings is not inconsistent with the recent decline in the U.S. national savings rate since this is a counterfactual exercise in which other factors that impact aggregate savings are held constant.

that our model generates a reasonable degree of insurance possibilities for agents. In this section, we provide a measure of the degree of insurance available in the model and compare it with the empirical literature. One way economists measure insurance is by computing the degree of pass-through from earnings to consumption. Formally, the pass-through coefficient from earnings to consumption is defined as the regression coefficient b of the following panel regression:

$$\Delta c_{i,t} = b\Delta y_{i,t} + \epsilon_{i,t},$$

where Δc_t denotes change in individual log consumption between $t-1$ and t and Δy_t denotes change in individual log earnings. The estimated coefficient b is expected to take values between 0 and 1. A pass-through coefficient of 0 would mean perfect insurance, whereas that of 1 would imply no insurance.

Computing the pass-through coefficient using model simulated data, we find it to be 0.19 in the 1967 steady state. This value is close to the pass-through coefficients implied by Blundell, Pistaferri, and Preston (2008) who use the Panel Study of Income Dynamics and Consumer Expenditure Survey data to analyze the evolution of the extent of partial insurance in the United States in the 1980s and early 1990s. Replicating the simple regression above gives an average value of around 0.2 for the pass-through from consumption to earnings in the 1980s in their work. We also calculate the pass-through coefficient in the 2010 steady state and find it to be 0.17. This decline in pass-through is also in line with Blundell, Pistaferri, and Preston (2008), who find that the consumption pass-through of earnings declined in the 1990s. The fact that our model generates reasonable pass-through values suggests that through endogenous labor supply, progressive taxation and self-insurance the model provides a realistic degree of insurance opportunities.

Table 6: Decomposition between Persistent and Transitory Components

	1967	2010	Risk overall	Persistent component	Transitory component
Skill premium	1.51	1.92	1.70	1.69	1.53

The first two columns report the skill premia in the 1967 and the 2010 steady states. The column 'Risk overall' reports the skill premium in the counterfactual exercise where wage risk parameters are set to their 2010 values but all the other factors remain at their 1967 values. The columns 'Persistent component' and 'Transitory component' report skill premia in the counterfactual exercises in which we only change the variances of the persistent components and transitory components to their 2010 values, respectively.

6.3   Two Decompositions

To shed more light at the main quantitative results, this section provides two decomposition exercises.

Persistent vs. Transitory Component. We have shown that changes in wage risk are quantitatively important for the skill premium. The wage processes have two components, a transitory component and a highly persistent component. The variances of both these shocks increased between 1967 and 2010. This section investigates the degree to which changes in each component affect the skill premium. We introduce the changes in the variances of transitory and persistent components between 1967 and 2010 separately (keeping all other factors at their 1967 values) and compute the skill premia in the corresponding economies.

These results are reported in Table 6. The changes in the persistent components of the wage processes of the skilled and unskilled agents account for most of the change in the skill premium arising from changes in risk. This is despite the fact that the increases in the variances of the transitory and persistent components are of similar magnitudes (see Table 3). The fact that the persistent component is more important for the skill premium is expected, since transitory shocks are well insured by precautionary savings in this economy, while persistent shocks are not. The increase in persistent shock variances then implies larger precautionary savings responses.

Wage Risk of Skilled vs. Unskilled Agents. Table 7 reports the results for the second decomposition exercise. The column entitled 'Skilled only' displays that the skill

Table 7: Decomposition Between Changes in Skilled and Unskilled Risk

	1967	2010	Risk overall	Skilled only	Unskilled only
Skill premium	1.51	1.92	1.70	1.63	1.57

The first two columns report skill premia in the 1967 and the 2010 steady states. The column 'Risk overall' reports the skill premium in the counterfactual exercise where wage risk parameters are set to their 2010 values but all the other factors remain at their 1967 values. The columns 'Skilled only' and 'Unskilled only' report skill premia in the counterfactual exercises in which we change wage risk parameters to their 2010 values only for skilled agents or unskilled agents, respectively.

premium increases to 1.63 if the only change relative to the 1967 steady state is the wage risk of the skilled agents. The last column of the table shows that the rise in unskilled agents' wage risk has a smaller but still significant effect on the skill premium. As shown in Table 3, skilled agents' wage risk has increased more (in particular, the volatility of the persistent component, which is more important for the skill premium as discussed above, has risen), and, hence, one expects a larger response in terms of precautionary savings and the skill premium. This turns out to be true despite the fact that there are relatively few skilled people in the 1967 economy, specifically, 13.56%.

6.4 Race Between Technology and Education

This paper does not claim that wage risk is the most important individual determinant of the skill premium. We acknowledge that skilled-biased technical change and the rise in the supply of skilled workers have individually been more important for the skill premium. We view this paper as proposing a novel idea that changes in wage risk can have a quantitatively significant effect on the skill premium.

We perform two additional counterfactual exercises which illustrate the importance of the skill-biased technical change and the rise in the supply of skilled workers for the skill premium in our model. In the first exercise, we solve for a steady state in which we keep all parameters as in 1967 and only change the fraction of skilled workers, π_s, from its 1967 value of 13.56% to its 2010 value of 31.69%. The resulting skill premium is 0.58, meaning that skilled workers have, on average, lower wages than unskilled workers.

Table 8: Risk Aversion

σ	1967	2010	Only Risk
1	1.51	1.88	1.62
2	1.51	1.92	1.70
3	1.51	1.98	1.81

The second row of this table reports skill premia in the model for the benchmark analysis with $\sigma = 2$. The first two columns report the skill premium in the 1967 and the 2010 steady states. The column 'Only Risk' reports the skill premium in the counterfactual exercise in which wage risk parameters are set to their 2010 values but all other factors remain at their 1967 values. The first and third rows report the same set of values for $\sigma = 1$ and $\sigma = 3$ cases.

In the second exercise, we solve for a steady state in which we only change the price of equipment, q, from its 1967 normalized value of 1 to its 2010 value of 0.1577. The resulting skill premium is 3.75.

6.5 Sensitivity to Risk Aversion

In the proposed mechanism, the link between wage risk and the 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 is to measure how sensitive our results are to the degree of risk aversion. To this end, this section repeats the main quantitative exercises for relative risk aversion coefficients of $\sigma = 1$ and $\sigma = 3$, in addition to the benchmark value of $\sigma = 2$. We recalibrate the internally calibrated parameters for each σ exercise. The results of the quantitative exercises are presented in Table 8.

Each row in Table 8 reports our findings for a different level of σ. The column entitled 2010 reports the model's prediction of the skill premium when all factors change to their 2010 levels. This column reveals that while $\sigma = 1$ and $\sigma = 2$ cases are virtually equally good in matching the overall rise in the skill premium, $\sigma = 3$ model overshoots this rise significantly. The last two columns report how the skill premium changes in the counterfactual where the wage risks faced by skilled and unskilled agents increase to their 2010 levels but all other factors remain unchanged at their 1967 levels. As expected, the effect of the rise in wage risk on the skill premium increases as the risk aversion parameter

Table 9: Skill Premium With and With Borrowing

	1967	2010	Only Risk
No borrowing, $a \geq 0$			
Skill premium	1.51	1.92	1.70
Borrowing, $a \geq -\bar{a}$			
Skill premium	1.51	1.93	1.69

The first row of this table report skill premia for the benchmark economy without any borrowing. The first two columns report the skill premia in the 1967 and the 2010 steady states. The column 'Only Risk' reports the skill premium in the counterfactual exercise where wage risk parameters are set to their 2010 values but all other factors remain at their 1967 values. The second row reports the same set of values for an alternative economy in which agents are allowed to borrow up to an exogeneous limit $\bar{a}$.

increases.

6.6 Borrowing Constraints

In the benchmark model, borrowing is ruled out. This section analyzes a version of the model in which borrowing is allowed, but limited by an exogeneous upper bound, i.e. $a \geq -\bar{a}$, where $\bar{a}$ is the maximum amount an agent can borrow. Heathcote, Storesletten, and Violante (2010) set $\bar{a}$ so that the fraction of people with negative wealth in their model is 15%, which approximates the corresponding data moment for their period of interest (1967-2000). We follow them and choose $\bar{a}$ to ensure that approximately 15% of the agents have negative wealth in 1967. This exogenous limit is held constant in the '2010' and the 'Only Risk' exercises. A comparison of the two rows of Table 9 shows that the main quantitative results are not affected by the presence of borrowing constraints.

7 Open Economy

The United States is not a closed economy, but, following the literature, earlier sections use that scenario as a useful benchmark. In a closed economy, the rise in aggregate savings coming from the rise in wage risk translates fully into higher capital stock. In an open economy, on the other hand, part of the rise in aggregate savings may be absorbed by the rest of the world, implying a smaller increase in aggregate capital stock, and hence, in

the skill premium. This means that the effect of a rise in wage risk on the skill premium may be smaller in an open economy. In this section, we illustrate to what extent the main mechanism is quantitatively significant when the United States is modelled as an open economy. A notable phenomenon that occurred in global financial markets within the period of interest is the significant drop in the net foreign asset position of the United States and the corresponding rise in U.S. assets in global portfolios or the so-called "global imbalances". Since the global imbalances phenomenon may affect the extent to which the rest of the world can absorb a potential rise in U.S. savings caused by a rise in wage risk, we also investigate the quantitative significance of our model with global imbalances.

We model the United States as a large open economy which interacts with another large open economy representing the rest of the world.[15] The rest of the world is modelled as a simple incomplete markets economy similar to Aiyagari (1994). The two economies are linked only through frictionless capital and goods markets; there is no labor mobility across the two countries.

7.1   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

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[15]Economists sometimes model the United States as a small open economy with a fixed interest rate. This assumption is not realistic but in many cases it provides computational or analytical convenience without affecting results. In our analysis, this is not the case since the relative size of the United States matters for what fraction of U.S. savings can be absorbed by the rest of the world. In particular, if one assumes that the United States is a small open economy, any change in U.S. savings would be fully absorbed by the rest of the world with no impact on the U.S. skill premium (assuming there are no frictions in international financial markets).

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

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 of which provides a reduced form way of introducing global imbalances into the model economy. In doing so, we are following the "global savings glut" hypothesis, which argues that global imbalances are caused by a shift in savings behavior in the rest of the world.[16] We calibrate two values for $\hat{\psi}$, one for the 1967 and another for the 2010 steady states, to ensure that the model matches 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, as 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 (the 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

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[16]The savings glut hypothesis was first put forth by Bernanke (2005). We follow Kehoe, Ruhl, and Steinberg (forthcoming) in modelling the savings glut as a change in foreigners' savings wedge.

of the world economies respectively, the market clearing for the world bond market is given by

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

There is no government in the rest of the world.

7.2 Calibration of the Two-Country Model

First, we calibrate the model to the 1967 world economy. Knowing the net international investment position of the two economies in 1967, one can calibrate the two economies separately.

The procedure for calibrating the model to the 1967 U.S. economy is the same as in the closed economy exercise, with one additional parameter to be determined; the world interest rate. The world interest rate is chosen (calibrated) to match the international investment position of the United States to its observed value of 10% of the U.S. GDP in 1967 (i.e., in net terms, Americans were holding a large amount of assets abroad). This implies a calibrated world real interest rate of 3.33%.[17]

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, the preference parameters are set to their values in the U.S. economy: $\hat{\sigma} = \sigma$ and $\hat{\beta} = \beta\delta$. Due to limited data availability, the parameters of the wage process $\sigma_{\hat{\varepsilon}}$, $\sigma_{\hat{\kappa}}$, and $\hat{\xi}$ are set to the weighted average of the corresponding values for Germany, the U.K., France, and Italy, as estimated by LeBlanc and Georgarakos (2013). These parameters are assumed to be constant between 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. The population of the rest of

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[17]There is one more difference in the calibration procedure of the United States as an open economy relative to the closed economy calibration of Section 4. In the closed economy calibration, the federal debt held by foreign and international investors is excluded when computing the government debt-to-GDP ratio. These debt holdings are included in the government debt-to-GDP ratio calculations in the open economy exercise. As a result, the debt-to-GDP ratio of the 1967 U.S. economy is calculated to be 0.26 as opposed to the value of 0.25 in the closed economy. For the same reason the U.S. debt-to-GDP ratio equals 0.60 in the 2010 open economy model as opposed to 0.32 in the closed economy model.

Table 10: 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	$\sigma_{\hat{\varepsilon}}$	0.0399			LG
R.O.W. variance of persistent shock	$\sigma_{\hat{\kappa}}$	0.0158			LG
R.O.W. persistence paramerter	$\hat{\xi}$	0.9335			LG
Calibration 1967					
World interest rate	R	3.33%	U.S. IIP/U.S. GDP	10%	Howard (1989)
R.O.W. savings wedge	$\hat{\psi}$	0.9115	R.O.W. IIP/U.S. GDP	-10%	Howard (1989)
R.O.W. TFP	$\hat{A}$	0.1724	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	2.42%	U.S. IIP/U.S. GDP	-16.3%	NIPA
R.O.W. savings wedge	$\hat{\psi}$	0.9186	R.O.W. IIP/U.S. GDP	16.3%	NIPA
R.O.W. TFP	$\hat{A}$	0.3055	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. R.O.W. refers to the rest of the world economy. LG, Maddison and NIPA refer to LeBlanc and Georgarakos (2013), Angus Maddison dataset and National Income and Product Accounts, respectively.

the world was 9.3 times the U.S. population in 1967. Normalizing 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, the savings wedge and the total factor productivity (TFP) in the rest of the world are chosen to match (i) the rest of the world net international investment position in 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. The rest of the world GDP for 1967 is calculated by summing up the GDPs of the 20 economies as they are reported in the Angus Maddison dataset.

Next, we recalibrate the model to 2010 to ensure that it matches the international investment positions in 2010. First, the world interest rate in 2010 is chosen 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 2.42% (in line with the global decline in capital returns). We still need to calibrate the population, the TFP and the savings 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 was about 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, the savings wedge and the TFP in the rest of the world are chosen to match (i) the net international investment position of the rest of the world in 2010 (16.3% of the U.S. GDP) and ii) the fraction of the GDP of the rest of the world to the U.S. GDP, which equals 2.25 in 2010 and is calculated exactly the same way as for 1967. The calibration procedure is summarized in Table 10 and the details of our empirical calculations are contained in the Appendix. Notice that $\hat{\psi}$ increases between 1967 and 2010. This rise is the model's way of generating the savings glut.

7.3 Model Fit

The results of the open economy exercise are reported in the third and fourth columns of Table 11. For comparison purposes we also report the findings from the closed economy exercise in the first and second columns. The skill premium increases from the calibrated value of 1.51 to 1.92 in the open economy exercise which is virtually identical to the change we observe in the benchmark closed economy exercise. This may seem surprising because, as the fourth row of Table 11 shows, the open economy model takes into account the fact that the assets held in the U.S. economy by foreigners (line 'Foreign assets') increase from -0.02 to 0.09 (from -10% to 17.5% of GDP) between 1967 and 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, for two reasons.

First, the inflow of foreign assets into the U.S. economy between 1967 and 2010 is relatively small compared to the size of the U.S. capital stock in 2010 (0.11 vs. 1.21). Second, as the third row of Table 11 shows, domestic savings in the open economy in 2010 are smaller than domestic savings in the closed economy, because the interest rate is

Table 11: Open Economy

	Closed		Open	
	1967	2010	1967	2010
Skill premium	1.51	1.92	1.51	1.92
IIP/GDP	0%	0%	10%	-17.5%
Total capital	0.43	1.21	0.43	1.21
Domestic assets	0.43	1.21	0.46	1.12
Foreign assets	0	0	-0.02	0.09
After-tax return	3.33%	2.38%	3.33%	2.42%

This table reports the model generated skill premium along with five other variables for the U.S. economy. The first two columns report these variables for the 1967 and the 2010 steady states for the closed economy version of the model, while the last two report them for the 1967 and the 2010 steady states for the open economy version. IIP/GDP refers to the U.S. net international investment position over GDP ratio. Domestic assets and Foreign assets refer to total domestic savings minus government debt and assets held in the U.S. economy by foreigners, respectively.

smaller in the open economy (consistent with the capital inflow). Foreign savings crowd out domestic savings and, hence, do not increase capital stock and the skill premium much. Thus, we conclude that whether one interprets the U.S. as a closed or a large open economy does not change the model's prediction regarding the overall rise in the skill premium by much.

7.4   Quantitative Significance of the Rise in Wage Risk

Next we investigate whether the rise in individual wage risk is still quantitatively important for the skill premium between 1967 and 2010 if the U.S. is modelled as an open economy. The third column of Table 12 reports that the rise in wage risk still contributes substantially to the rise in the skill premium: if the U.S. wage risk is the only factor allowed to change, and all other factors in the United States and the rest of the world remain constant, the skill premium in the United States would still go up by 11 percentage points (see the column "Only Risk"). The effect of the rise in wage risk on the skill premium is smaller than it is in the closed economy, because in an open economy part of the rise in aggregate savings is absorbed by the rest of the world. As a result, the stock of equipment capital increases only by 8% (relative to the 20% in the closed economy exercise).

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Table 12: Open Economy Decomposition

	1967	2010	Only Risk	Risk + Savings glut
Skill premium	1.51	1.92	1.63	1.66
Change			0.11	0.14

The first two columns of this table report skill premia in the 1967 and the 2010 steady states for the open economy version of the model. The column 'Only Risk' reports the skill premium in the counterfactual exercise where wage risk parameters are set to their 2010 values but all the other factors are at their 1967 values. The column 'Risk + Savings glut' reports the skill premium in the exercise in which wage risk parameters are set to their 2010 values but all the other factors are at their 1967 values for the U.S. economy and the preference parameter for the rest of the world, $\hat{\psi}$, is set to its 2010 value. The second row of the 'Only Risk' and the 'Risk + Savings glut' columns report the changes in the skill premium in the 'Only Risk' and the 'Risk + Savings glut' exercises relative to 1967 economy, respectively. Numbers may not add up due to rounding.

Notice that in the counterfactual exercise above the rest of the world absorbs a large fraction of the increase in U.S. (precautionary) savings because the rest of the world economy is kept as it was in 1967. In particular, the rise in the savings in the rest of the world (the savings glut) is not modelled. As an alternative exercise, we conduct the "Only Risk" exercise in a world in which we simulate the savings glut by increasing the rest of the world economy's preference parameter $\hat{\psi}$ from its calibrated level in 1967 to 2010. The last column of Table 12 shows that the rise in wage risk increases the skill premium by 14 percentage points in this case. The effect of the rise in wage risk on the skill premium is larger in this case since, with the savings glut, the rest of the world absorbs the rise in U.S. savings (coming from the rise in U.S. wage risk) to a lesser degree.

8 Endogenous Skill Supply

In the baseline environment, the fraction of skilled and unskilled agents are assumed to be fixed since the main focus of this paper is the relative prices of labor given the observed relative supply of skilled agents. In particular, in the counterfactual exercise in which only risk changes, we do not allow for skill supplies to change. This section provides 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.

Education. In this version of the model, agents make education decisions at the

beginning of their lives, just before they enter the labor market and before they draw the first wage shocks. They can choose to pursue a college degree, in which case they will be called skilled agents, $i = s$, or a lower level of education, 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 this cost to the benefit of attaining a college degree, which is simply the net present utility gain of receiving the skilled wage rather than the unskilled wage in each date and state after entering the labor market. Let $E_{i,0}[V_i(z_i, 0)]$ be the beginning of the lifetime 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 an endogenous variable in this section. The rest of the economic environment is identical to the one developed in the model section and will not be described here.

To conduct quantitative work, the cost distribution for attending college needs to be specified. We assume that the utility cost of attending college is distributed according to an exponential distribution with parameter m, a pdf, $f(\psi) = me^{-m\psi}$, and a cdf, $F(\psi) = 1 - e^{m\psi}$. 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

Table 13: Endogenous Skill Supply

	Exogenous		Endogenous	
	1967	Only Risk	1967	Only Risk
Skill premium	1.51	1.70	1.51	1.85
Change		0.18		0.34
Fraction skilled	13.56%	13.56%	13.56%	12.58%

This table reports the skill premium along with the fraction of skilled agents in the model economy. The first column reports these variables for the 1967 steady state for the benchmark exogenous skill supply economy. The second column reports them for the counterfactual exercise where wage risk parameters are set to their 2010 values but all the other factors are at their 1967 values. The last two columns report the values of the same set of variables for the endogenous skill supply economy. Numbers may not add up due to rounding.

at most $\bar{\psi}$ is equal to π_s^{67} in 1967. Thus, we calibrate m by setting $F(\bar{\psi}) = \pi_s^{67}$.[18]

The results of the "Only Risk" counterfactual exercise under endogenous skill supply are summarized in the last two columns of Table 13. For comparison purposes, the table also reports the benchmark exogenous skill supply exercise in the first two columns of Table 13. The effect of the rise in wage risk on the skill premium is larger in the endogenous skill supply exercise (34 vs. 18 percentage points). This finding might seem surprising. In particular, we know from the exogenous skill supply analysis that the rise in wage risk increases the skill premium (from 1.51 to 1.70). Other things being equal, an increase in the skill premium makes attaining a college degree more desirable. Therefore, one may expect that, with endogenous skills, a higher fraction of the population would attend college, which would then dampen the rise of the skill premium. However, recall from Table 3 that wage risk has increased more for skilled than for unskilled agents, making college education less attractive. Overall, attending college could become more or less desirable depending on which of the two effects dominates. It turns out that, under our parameterization, the latter effect dominates and fewer people attend college in the 'Only Risk' exercise as the last row of Table 13 shows. This increases the skill premium further.

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[18]The quantitative results are almost identical if, instead of being exponential, the utility cost distribution F is assumed to be uniform $U[0, m]$ and one calibrates m to the same target, i.e. so that $F(\bar{\psi}) = \pi_s^{67}$.

9 Conclusion

This paper proposes a mechanism through which a rise in individual wage risk leads to an increase in the skill premium. Intuitively, a rise in uninsured wage risk increases precautionary savings. The resulting rise in the capital stock increases the skill premium due to capital-skill complementarity. To evaluate the significance of this mechanism, we build a quantitative macroeconomic model with incomplete markets and capital-skill complementarity. The rise in wage risk observed in the United States between 1967 and 2010 increases the skill premium by at least 10 percentage points (25% of the observed change) in all the parameterizations and specifications of the model. We conclude that changes in wage risk can have a quantitatively important effect on the skill premium.

References

ACEMOGLU, D. (1998): "Why Do New Technologies Complement Skills? Directed Technical Change And Wage Inequality," *The Quarterly Journal of Economics*, 113(4), 1055–1089.

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.

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.

BLUNDELL, R., L. PISTAFERRI, AND I. PRESTON (2008): "Consumption Inequality and Partial Insurance," *American Economic Review*, 98(5), 1887–1921.

BUERA, F. J., J. P. KABOSKI, AND R. ROGERSON (2015): "Skill-Biased Structural Change and the Skill-Premium," Discussion paper.

BURSTEIN, A., E. MORALES, AND J. VOGEL (2015): "Accounting for Changes in Between-Group Inequality," NBER Working Papers 20855, National Bureau of Economic Research, Inc.

BURSTEIN, A., AND J. VOGEL (forthcoming): "International Trade, Technology, and the Skill Premium," *Journal of Political Economy*.

CARROLL, C. D. (1994): "How Does Future Income Affect Current Consumption?," *The Quarterly Journal of Economics*, 109(1), 111–147.

CASELLI, F. (1999): "Technological Revolutions," *American Economic Review*, 89(1), 78–102.

CASTANEDA, A., J. DÍAZ-GIMÉNEZ, AND J.-V. RÍOS-RULL (2003): "Accounting for the U.S. Earnings and Wealth Inequality," *Journal of Political Economy*, 111(4), 818–857.

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.

DEATON, A. (1991): "Saving and Liquidity Constraints," *Econometrica*, 59(5), 1221–1248.

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

DOMEIJ, D., AND L. LJUNGQVIST (2006): "Wage Structure and Public Sector Employment: Sweden versus the United States 1970-2002," SSE/EFI Working Paper Series in Economics and Finance 638, Stockholm School of Economics.

DUFFY, J., C. PAPAGEORGIOU, AND F. PEREZ-SEBASTIAN (2004): "Capital-Skill Complementarity? Evidence from a Panel of Countries," *Review of Economics and Statistics*, 86(1), 327–344.

FALLON, P. R., AND P. R. G. LAYARD (1975): "Capital-Skill Complementarity, Income Distribution, and Output Accounting," *Journal of Political Economy*, 83(2), 279–302.

FLUG, K., AND Z. HERCOWITZ (2000): "Equipment Investment and the Relative Demand for Skilled Labor: International Evidence," *Review of Economic Dynamics*, 3, 461–485.

GALOR, O., AND D. TSIDDON (1997): "Technological Progress, Mobility, and Economic Growth," *American Economic Review*, 87(3), 363–382.

GOLDIN, C., AND L. F. KATZ (2008): *The Race between Education and Technology.* Cambridge, MA: Harvard University Press.

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

——— (2012): "Trends in the Transitory Variance of Male Earnings: Methods and Evidence," *Journal of Human Resources*, 47(1), 204–236.

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.

GREENWOOD, J., AND M. YORUKOGLU (1997): "1974," *Carnegie-Rochester Conference Series on Public Policy*, 46(1), 49–95.

GRILICHES, Z. (1969): "Capital-Skill Complementarity," *Review of Economics and Statistics*, 51(4), 465–468.

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., S. OZKAN, AND J. SONG (2014): "The Nature of Countercyclical Income Risk," *Journal of Political Economy*, 122(3), 621–660.

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.

——— (2017): "Optimal Tax Progressivity: An Analytical Framework," *forthcoming, Quarterly Journal of Economics*.

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 (2017): "Wage Volatility and Changing Patterns of Labor Supply," Discussion paper.

HORNSTEIN, A., AND P. KRUSELL (1996): "Can Technology Improvements Cause Productivity Slowdowns?," in *NBER Macroeconomics Annual 1996, Volume 11*, NBER Chapters, pp. 209–276. National Bureau of Economic Research, Inc.

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.

KARABARBOUNIS, L., AND B. NEIMAN (2014): "The Global Decline of the Labor Share," *The Quarterly Journal of Economics*, 129(1), 61–103.

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 (forthcoming): "Global imbalances and structural change in the United States," *Journal of Political Economy*.

KIMBALL, M. S. (1990): "Precautionary Saving in the Small and in the Large," *Econometrica*, 58(1), 53–73.

KOPECKY, K., AND R. SUEN (2010): "Finite State Markov-chain Approximations to Highly Persistent Processes," *Review of Economic Dynamics*, 13(3), 701–714.

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.

Lane, P. R., and G. M. Milesi-Ferretti (2007): "The external wealth of nations mark II: Revised and extended estimates of foreign assets and liabilities, 1970-2004," *Journal of International Economics*, 73(2), 223 – 250.

Larrain, M. (2015): "Editor's Choice Capital Account Opening and Wage Inequality," *Review of Financial Studies*, 28(6), 1555–1587.

LeBlanc, J., and D. Georgarakos (2013): "How Risky is their Income? Labor Income Processes in Europe," Working paper.

Pijoan-Mas, J. (2006): "Precautionary Savings or Working Longer Hours?," *Review of Economic Dynamics*, 9(2), 326–352.

Ríos-Rull, J.-V., and R. Santaeulàlia-Llopis (2010): "Redistributive shocks and productivity shocks," *Journal of Monetary Economics*, 57(8), 931–948.

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.

Violante, G. L. (2002): "Technological Acceleration, Skill Transferability, and the Rise in Residual Inequality," *The Quarterly Journal of Economics*, 117(1), 297–338.

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

Appendix

A   Data Construction

A.1   Skill Premium

Heathcote, Perri, and Violante (2010) use the Current Population Survey (CPS) administered by the U.S. Census Bureau and the U.S. Bureau of Labor Statistics data to compute the skill premium for 1967-2005. We use their methodology and extend the time series of the U.S. skill premium until 2010. Our main data source is CPS provided by Integrated Public Use Microdata Series (IPUMS). We focus on the March releases of each survey from 1967 to 2010. We focus on the population of working age males, thus we drop people younger than 25 or older than 60.

Our main variable of interest is the skill premium, defined as the average of the hourly wage rates of skilled agents over the average hourly wage rate of unskilled agents. We follow Krusell, Ohanian, Ríos-Rull, and Violante (2000) and define skilled agents as those who have at least 16 years of schooling. This corresponds to at least '4 years of schooling' in surveys conducted prior to 1992 and 'bachelor's degree' in surveys conducted after 1992. (The variable we use to sort people into skilled and unskilled is called 'educ' For an agent to be specified as skilled, we require that 'educ' takes at least the value of 110, which corresponds to at least 16 years of schooling.) The hourly wage rate of an agent is calculated by dividing her annual labor income by her annual total hours worked. A person's labor income equals the sum of her wage and salary income (variable 'incwage') and 2/3 of her non-farm business income (variable 'incbus'). Total hours worked is computed by multiplying average hours worked per week (variable 'uhrsworkly') and total number of weeks worked (variable 'wkswork1').

We drop those who work a very small number of hours (less than 260) and those who earned very small annual amounts (less than $100). We also drop those giving inconsistent answers to questions about labor income and hours worked (i.e. those who claim they received labor income, but who did not work or vice versa). Finally, we drop

individuals whose hourly wage rate is less than half of the federal minimum wage.

A.2 Closed Economy

Skill biased technical change. We use the declining price of equipment as a measure of skill biased technical change. The price of equipment is calculated using the series PERIC (Relative Price of Equipment, Index 2009=1, Annual, Seasonally Adjusted) in the St. Louis FED database, which is an update of the time series constructed in DiCecio (2009). We normalize the price of equipment to 1 in 1967 (rather than 2009 as the original time-series does) and recover the corresponding value for 2010.

Fraction of skilled agents. The fraction of skilled agents is calculated using CPS. There was a change in terms of how CPS reports educational attainment in 1992. We follow Krusell, Ohanian, Ríos-Rull, and Violante (2000) and define the fraction of skilled agents as follows. For 1967, it is the ratio of males aged 25 and older with earnings and 4 years or more of college divided by the total number of males aged 25 and older with earnings in Table P-17. For 2010, it is the ratio of males aged 25 and older with earnings and a bachelor's degree or more divided by the total number of males aged 25 and older with earnings in Table P-16.

Government consumption-to-GDP ratio. The government consumption-to-output ratio is recovered from the National Income and Product Accounts (NIPA) data. It is defined as the ratio of nominal government consumption expenditure (line 15 in NIPA Table 3.1) to nominal GDP (line 1 in NIPA Table 1.1.5).

Government debt-to-GDP ratio. The government debt to GDP ratio is recovered as the difference between the series FYGFGDQ188S (Federal Debt Held by the Public as Percent of Gross Domestic Product, Percent of GDP, Quarterly, Seasonally Adjusted) minus the series HBFIGDQ188S (Federal Debt Held by Foreign and International Investors as Percent of Gross Domestic Product, Percent of GDP, Quarterly, Seasonally Adjusted) in the St. Louis FED database. These time series are quarterly. We construct

the annual statistics by averaging over the particular year. The earliest data is available for 1970, so we use 1970 government-debt-to-GDP ratio in place of 1967 value.

Labor share. The labor share is computed from NIPA using the methodology described in Ríos-Rull and Santaeulàlia-Llopis (2010) and for details, we refer the reader to that paper. It offers several alternative ways of calculating the labor share. We use the following: we first calculate what Ríos-Rull and Santaeulàlia-Llopis (2010) call "unambiguously capital income" and "unambiguously labor income." Income which cannot be unambiguously classified as labor or capital income is then divided between capital and labor using the ratio between capital and labor income in unambiguously assigned income. To get the labor share, labor income is then divided by GDP.

Capital-to-output ratio. Housing is excluded from both output and capital when calculating the capital-to-output ratio. For this calculation, output is defined using Table 1.5.5 in NIPA as GDP (line 1) net of Housing and utilities (line 16) and Residential investment (line 41). Capital stock is calculated using the Fixed Asset Tables (FAT), Table 1.1 as the sum of the stocks of private and government structure and equipment capital (line 5 + line 6 + line 11 + line 12). The resulting annual capital-output ratio varies between 1.8 and 2.4 during 1967-2010. To abstract from short-term fluctuations, the capital-output ratio value of 2, which we use as a calibration target, is computed by taking the average of annual capital-output ratios over this period.

A.3   Additional Calculations for Open Economy

International investment position (IIP). The net international investment position of the United States as a fraction of the U.S. Gross Domestic Product (GDP) is constructed using two data sources. The first is the External Wealth of Nations Mark II database from Lane and Milesi-Ferretti (2007) which provides the IIP for the U.S. economy for 1976-2010 (The original paper included U.S. IIP time series for 1976-2004. The 2010 U.S. IIP value comes from an update of the authors' work which can be retrieved at the following url: "http://www.philiplane.org/EWN/"). The series "official IIP" re-

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ports the country's net international investment position (inclusive of gold holdings) as reported by national authorities in current dollars. The second data source is the National Income and Product Accounts (NIPA) Table 1.5.5 which provides the GDP series also in current dollars. We construct the 2010 value for IIP/GDP by dividing 2010 U.S. IIP by 2010 U.S. GDP. The resulting number is -16.3%. Since the time series for U.S. IIP starts in 1976, we cannot directly measure the IIP-to-GDP ratio for 1967. According to Howard (1989) (see Figure 1 on page 1a), the U.S. IIP as a fraction of GDP was stable in the decade before 1976. Therefore, IIP/GDP in 1967 is set equal to IIP/GDP in 1976. This value, which is calculated by dividing 1976 U.S. IIP by 1976 U.S. GDP, equals 10%.

U.S. Government-debt-to-GDP ratio for an open economy model. The empirical definition of the government-debt-to-GDP ratio differs between a closed and an open economy. The government-debt-to-GDP ratio for the 1967 and 2010 U.S. economy for the open economy exercise is taken directly from the Federal Reserve Bank of St. Louis Database. We use their time series called FYGFGDQ188S (Federal Debt Held by the Public as Percent of Gross Domestic Product, Percent of GDP, Quarterly, Seasonally Adjusted). This time series includes includes U.S. debt held by foreign and international investors. This time series is quarterly. We construct the annual statistics by averaging over the particular year. The earliest data is available for 1970, so we use 1970 government-debt-to-GDP ratio in place of the 1967 value. This value is approximately 26%. The value for 2010 is approximately 60%.

Rest of the world economy (R.O.W.). The rest of the world economy is modelled as 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. Table 14 below provides the list of these countries.

Relative population sizes of the U.S. economy vs. the R.O.W. economy. The population sizes of the U.S. and the R.O.W. economies for 1967 and 2010 are constructed using Table 1 of the Historical Statistics for the World Economy: 1-2003 AD (Angus

Table 14: List of Top 20 Trading Partners of the United States

1. Canada	5. Germany	9. Brazil	13. Netherlands	17. Hong Kong
2. China	6. South Korea	10. Taiwan	14. Italy	18. Singapore
3. Mexico	7. United Kingdom	11. India	15. Belgium	19. Malaysia
4. Japan	8. France	12. Saudi Arabia	16. Switzerland	20. Ireland

This table reports the top 20 trading partners (ordered by trade volume) of the United States as of December 2014 as reported by the U.S. International Trade Administration.

Maddison) dataset. The population size of the United States is taken directly from Table 1. To construct the total population of the R.O.W. economy, we sum the population sizes of the top 20 trading partners of the United States using again Table 1 of the same dataset.

Relative GDPs of the U.S. economy vs. the R.O.W. economy. The GDP of the U.S. and the R.O.W. economies for 1967 are constructed using Table 2 of the Angus Maddison dataset. GDP of the United States is taken directly from Table 1. To construct the GDP of the R.O.W. economy, we sum the GDPs of the top 20 trading partners of the United States as they are given in Table 1 of the same dataset. We use the same procedure but a different data source to obtain the GDPs of the U.S. and the R.O.W. economies for 2010, since the GDP series in the Angus Maddison dataset end in 2003. The dataset that we use for 2010 GDP is the WorldBank World Development Indicators.

Abstrakt

V posledních pěti dekádách ve Spojených Státech výrazně vzrostla vzdělanostní prémie. Ve stejné době došlo k nárůstu mzdové rizikovosti. Tento článek navrhuje mechanismus, díky kterému nárůst mzdové rizikovosti vede k nárůstu vzdělanostní prémie. Intuitivně vede nárůst mzdové rizikovosti ke zvýšení preventivních úspor, což vede na agregátní úrovni k nárůstu investic a kapitálu. Díky komplementaritě mezi kapitálem a vzdělanou pracovní silou pak zvýšení množství kapitálu zvyšuje vzdělanostní prémii. V rámci kvantitativního makroekonomického modelu jsme zjistili, že narůst rizikovosti mezd mezi lety 1967 a 2010 vede k výraznému nárůstu vzdělanostní prémie. Tento závěr je robustní v mnoha verzích našeho modelu.