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.

JEL classification: E25, J31.
Keywords: Skill premium, wage risk, capital-skill complementarity, precautionary savings.

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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 (2019), 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 wage risk leads to an increase in the skill premium and show 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 people face uninsured idiosyncratic wage risk. Capital-skill complementarity is built in by assuming a production function that features a

[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).

higher degree of complementarity between equipment capital and skilled labor than between equipment capital and unskilled labor, as documented for the United States by Krusell, Ohanian, Ríos-Rull, and Violante (2000). We model the United States as an open economy as part of the rise in aggregate savings (due to the rise in wage risk) may be absorbed by the rest of the world, which would imply that the resulting impact on the skill premium would be more modest. 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 the 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 (2019), as well as the changes in four other factors. Two of these factors have found significant support in the literature in terms of determining the evolution of the skill premium. These are technological advancements that favor skilled workers (skill-biased technical change) and the rise of the relative supply of skilled workers.[3] Following Krusell, Ohanian, Ríos-Rull, and Violante (2000), skill-biased technical change is modeled as a decline in the price of equipment. The other two factors that change between 1967 and 2010 are international capital flows and government policy. Having introduced changes in the structure of wage risk, technology, relative supply of skilled workers, international capital flows, and government policy, we solve for the new steady state, which corresponds to 2010.

The model generates a 40 percentage point increase in the skill premium, from 1.50 in 1967 to 1.90 in 2010 which coincides with the observed increase of 40 percentage points in the U.S. skill premium over the same time period. In addition, the model matches well the trends in main macroeconomic and distributional moments between 1967 and 2010. We

[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.

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 the rise in wage risk by calculating how much it 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 the 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 1.60, an increase of 10 percentage points relative to the 1967 steady state. In an alternative exercise, we feed in the changes in technology, the relative supply of skilled agents, government policy and international capital flows that are observed 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 1.84, which is 6 percentage points shy of the model implied skill premium for 2010. A comparison of these numbers to the observed (or the model implied) 40 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 (i) an extension to an alternative version of the model with heterogenous discount factors aimed at providing a better match of the wealth distribution, (ii) sensitivity analyses with respect to agents' risk aversion and elasticity of labor supply, and (iii) and an extension to a model with endogenous skill supply.

In our model, the rise in wage risk between 1967 and 2010 increases aggregate savings through the precautionary savings channel. This is not inconsistent with the fact that the U.S. national saving rate declined over the same period since there have been other factors at play, most prominently the global decline in interest rates. These other factors have been more important in determining the change in the saving rate over this period in which the United States went from being a net creditor to a net debtor in international capital markets.

We also conduct counterfactual exercises to evaluate the significance of other factors in contributing to the rise of the skill premium. Our results confirm 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. We also find that the rise in capital inflows into the United States between 1967 and 2010 contributed, albeit modestly, to the rise in the skill premium. This finding is in line with Larrain (2015) who estimates the impact of capital account opening on the skill premium for a panel of countries.

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, Rogerson, and Vizcaino (forthcoming) 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.[4] 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). Guvenen 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

[4] 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.

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 are Heathcote, Storesletten, and Violante (2010) and Hong, Seok, and You (2019). 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 (2019) 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.[5]

Finally, our finding regarding the impact of international capital inflows on the skill premium is related to a literature that studies the effect of trade liberalization on inequality. Using a Ricardian model of international trade, Burstein and Vogel (2017) show that reductions in trade costs can generate significant increases in the skill premium in almost all the countries in their sample. Similarly, Parro (2013) finds that trade liberalization increases the skill premium in a model with capital-skill complementarity.[6] Unlike these papers which analyze the impact of patterns of intratemporal trade on the skill premium, our counterfactual investigates the effect of capital flows on the skill premium.

The rest of this paper is structured as follows. Section 2 describes the model in detail. Section 3 explains how the model is calibrated to the 1967 U.S. economy. Section 4 summarizes the changes in the skill premium, wage risk and other factors between 1967 and 2010. Section 5 discusses our main quantitative findings. Section 6 concludes. An online appendix

[5]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.

[6]See also Helpman, Itskhoki, and Redding (2010) and Cosar, Guner, and Tybout (2016) for papers that analyze the effect of trade liberalization on wage inequality more broadly defined.

contains, among other things, the equilibrium definition used in the paper, the details of our empirical calculations, sensitivity analysis, and an extension in which skill supply is endogeneous.

2 Model

This section develops an infinite horizon open economy growth model with two types of capital (structure and equipment capital), two types of labor (skilled and unskilled), consumers, a representative 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 modeled.

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 while unskilled agents only work 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 fractions 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. People with 4 years of college education or more are classified as skilled agents while the rest of the people are classified as unskilled agents. Section 4 describes the increase in the relative supply of skilled workers, π_s, observed between 1967 and 2010.

In addition to heterogeneity across 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 $w_i \cdot z_i$. The stochastic processes that govern this wage risk are allowed to be different for the two skill groups. The logarithm of z_i is modeled 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 $\sigma_{i,\theta}$.

The change in idiosyncratic wage risk is modeled by allowing the variances $\sigma_{i,\varepsilon}$ and $\sigma_{i,\kappa}$ to change over time. Section 4 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_i's 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. Modeling elastic labor supply is especially important since this margin gives agents an additional tool to insure themselves against income shocks.

Technology. Output is produced using a constant returns to scale aggregate production function, $Y = F(K_s, K_e, L_s, L_u)$, where K_s is structure capital, K_e is equipment capital, L_s is effective skilled labor, and L_u is effective unskilled labor. Structure and equipment capital depreciate at rates δ_s and δ_e, respectively.

The production function we use in our quatitative analysis features equipment-skill complementarity, meaning that the degree of complementarity between equipment capital and skilled labor is higher than that between equipment capital and unskilled labor. Equipment-skill complementarity implies that an increase in the stock of equipment capital increases the ratio of the marginal product of skilled labor to the marginal product of unskilled labor. Assuming competitive factor markets, this in turn implies that the skill premium, i.e., the ratio of skilled to unskilled wages, is increasing in equipment capital. In contrast, structure capital is neutral in terms of its complementarity with skilled and unskilled labor. These assumptions on technology are consistent with the empirical estimates 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 supply of skilled labor leads to a decrease in the skill premium. An increase in the supply of unskilled labor 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 Krusell, Ohanian, Ríos-Rull, and Violante (2000), we model skill-biased technical change as a decline in q over time and abstract from factor augmenting technical change. Section 4 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:

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

where $r_{s,t}$ and $r_{e,t}$ are the rental rates of structure and equipment capital, and $w_{u,t}$ and $w_{s,t}$ are 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. Since 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 capital income is taxed at the consumer level. The government uses a sequence of non-linear functions $\{T_t(y)\}_{t=0}^{\infty}$ to tax labor income, where y is labor income and $T_t(y)$ is the tax paid by the consumer. Allowing for non-linearity of the tax 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 its tax revenue to finance a stream of expenditures $\{G_t\}_{t=0}^{\infty}$ and to repay government debt $\{D_t\}_{t=0}^{\infty}$.

Asset Market Structure. In the baseline model, consumers are not allowed to borrow. They save in terms of the two types of capital, government bonds, and foreign assets. In the absence of aggregate shocks, the returns to all of these assets must yield the same after-tax return in equilibrium. As a result, one does not need to distinguish between savings via different types of assets in the consumers' problem. In every period, the equilibrium interest rate is such that the total domestic asset holdings is equal to the sum of government debt, total capital stock in the economy and the net foreign asset position (NFAP). The latter equals the foreign assets owned by domestic citizens minus the domestic assets owned by foreigners. In the quantitative analysis, we calibrate the model so that the NFAP-to-wealth ratio in the model matches that of the U.S. economy in 1967 and 2010.

Stationary Equilibria. Our quantitative analysis focuses on the comparison of stationary competitive equilibria where one stationary equilibrium corresponds to 1967 and another one to 2010. For that reason, rather than giving a general definition of competitive equilibrium, we only define stationary recursive competitive equilibria (SRCE). The definition is relegated to Online Appendix A.

3 Calibrating the Model to 1967

In order to evaluate the quantitative significance of the increase in wage risk on the skill premium, we first calibrate the model economy. This section describes the calibration procedure. One period in the model corresponds to one year. We first fix a number of parameters to values from the data or from the literature. These parameters are summarized in column '1967' 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. The year 1967 is chosen as the initial steady state since 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, educational attainment and the idiosyncratic productivity processes. The details of our data work are provided in Online Appendix B.

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

$$Y = F(K_s, K_e, L_s, L_u) = K_s^{\alpha} \left(\nu \left[\omega K_e^{\rho} + (1-\omega) L_s^{\rho} \right]^{\frac{\eta}{\rho}} + (1-\nu) L_u^{\eta} \right)^{\frac{1-\alpha}{\eta}}. \tag{3}$$

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 income share of structure capital is given by α. 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, 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:

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

Here, σ is the coefficient of relative risk aversion in consumption and $1/\gamma$ is the Frisch elasticity of labor supply.[7] In the benchmark case, we use $\sigma = 2$ and $\gamma = 2$ and calibrate ϕ to match the average labor supply. Agents in the model are born at the real life age of 25

[7] This utility specification belongs to a class of preferences introduced by King, Plosser, and Rebelo (1988). Following Shimer (2009), we choose this specific functional form because it is not only balanced growth path compatible but it also offers a free parameter, γ, that controls the Frisch elasticity of labor supply. When $\sigma = 1$, these preferences are additively separable of the form $\log(c) - \phi \frac{l^{1+\gamma}}{1+\gamma}$.

Table 1: Benchmark Parameters

Parameter	Symbol	1967	2010	Source
Preferences and demography				
Relative risk aversion parameter	σ	2	2	
Inverse Frisch elasticity	γ	2	2	
Probability of survival	δ	0.978	0.978	CDR
Fraction of skilled workers	π_s	0.1356	0.3169	CPS
Technology				
Structure capital depreciation rate	δ_s	0.056	0.056	GHK
Equipment capital depreciation rate	δ_e	0.124	0.124	GHK
Share of structure capital in output	α	0.117	0.117	KORV
Measure of elasticity of substitution between equipment capital K_e and unskilled labor L_u	η	0.401	0.401	KORV
Measure of elasticity of substitution between equipment capital K_e and skilled labor L_s	ρ	-0.495	-0.495	KORV
Price of equipment capital	q	1	0.1489	D, FRED
Residual wage risk				
Skilled agents				
Persistence of the AR(1) component	ξ_s	0.9834	0.9834	HSY
Variance of the transitory shock	$\sigma^2_{s,\varepsilon}$	0.0201	0.0916	HSY
Variance of the persistent shock	$\sigma^2_{s,\kappa}$	0.0089	0.0229	HSY
Variance of the persistent component for entrants	$\sigma^2_{s,\theta}$	0.1172	0.1172	HSY
Unskilled agents				
Persistence of the AR(1) component	ξ_u	0.9859	0.9859	HSY
Variance of the transitory shock	$\sigma^2_{u,\varepsilon}$	0.0259	0.0739	HSY
Variance of the persistent shock	$\sigma^2_{u,\kappa}$	0.0073	0.0146	HSY
Variance of the persistent component for entrants	$\sigma^2_{u,\theta}$	0.1488	0.1488	HSY
Government polices				
Labor tax progressivity	τ_l	0.124	0.095	FN
Overall structure capital tax	τ_s	0.567	0.422	A, G
Overall equipment capital tax	τ_e	0.499	0.371	A, G
Government consumption	G/Y	0.16	0.16	NIPA
Government debt	D/Y	0.26	0.60	FRED

This table reports the benchmark parameters taken either directly from the literature or the data. The column entitled '1967' and '2010' report the values of these parameters for the 1967 and 2010 steady states, respectively. The acronyms A, CDR, D, FN, G, GHK, HSV, HSY, and KORV stand for Auerbach (1983), Castaneda, Díaz-Giménez, and Ríos-Rull (2003), DiCecio (2009), Ferrière and Navarro (2018), Gravelle (2011), Greenwood, Hercowitz, and Krusell (1997), Heathcote, Storesletten, and Violante (2017), Hong, Seok, and You (2019), and Krusell, Ohanian, Ríos-Rull, and Violante (2000), respectively. CPS, FRED and NIPA stand for the Current Population Survey of the U.S. Census Bureau (2021), the Federal Reserve Economic Data database of the Federal Reserve Bank of St. Louis (2021), and the National Income and Product Accounts or the U.S. Bureau of Economic Analysis (2021), respectively.

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, is 0.1356 in the Current Population Survey (CPS) data of the U.S. Census Bureau (2021). 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 modeled as the sum of a persistent autoregressive component and a transitory component as given by equations $(1)-(2)$. Hong, Seok, and You (2019) use the Panel Study of Income Dynamics data and estimate the parameters of these processes using the same methodology as Heathcote, Storesletten, and Violante (2010). We use the estimates provided by Hong, Seok, and You (2019) for two reasons. First, Hong, Seok, and You (2019) provide estimates until 2010, which allows us to conduct our quantitative exercise over a longer period of time. Heathcote, Storesletten, and Violante (2010) provide these estimates only until 2000. In addition, Hong, Seok, and You (2019) estimate the parameters of the wage processes for each skill group separately. This is important since savings responses to changes in wage risk can differ across skill groups.

Following Heathcote, Storesletten, and Violante (2010), Hong, Seok, and You (2019) assume that the persistence parameters ξ_i and the variances of the initial draws of the persistent components $\sigma^2_{i,\theta}$ are constant over time. The variances of the shocks of the persistent components $\sigma^2_{i,\kappa}$ and the variance of the shocks of the transitory components $\sigma^2_{i,\varepsilon}$ are allowed to change over time, and Hong, Seok, and You (2019) estimate these latter parameters for all years in the PSID sample. 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 ten years between 1967 and 1976 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, $\sigma^2_{i,\theta}$, and the persistence parameters ξ_i are also taken from Hong, Seok, and You (2019). 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 (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 1967-2012, as reported in the National Income and Product Accounts (NIPA) data of the U.S. Bureau of Economic Analysis (2021). We set the government debt-to-GDP ratio to 26% for 1967 as reported by the FRED Database of Federal Reserve Bank of St. Louis (2021). This number corresponds to U.S. federal government debt held by the domestic private sector and foreign investors.

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.[8] 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 $\tau_s = 1 - 0.85 \cdot (1 - 0.49) = 56.7\%$ and an overall tax on equipment capital of $\tau_e = 1 - 0.85 \cdot (1 - 0.41) = 49.9\%$.

As for labor income taxes, modeling 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

[8] 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.

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 Guner, Kaygusuz, and Ventura (2014) and Heathcote, Storesletten, and Violante (2017), and assume that tax liability given labor income y is defined as $T(y) = y - \chi y^{1-\tau_l}$. In this formula, τ_l controls the progressivity of the tax code. Since we measure income y in multiples of the average income in the economy, $1 - \chi$ is the average tax rate of the mean income individual. Using longitudinal IRS (Internal Revenue Service) data, Ferrière and Navarro (2018) estimate that the average $\tau_l = 0.124$ in the 1960s. We use this estimate and set χ to clear the government budget in steady state.

International Capital Flows. In the data, the net foreign asset position of the U.S. as a fraction of U.S. national wealth (which, by definition, equals the total domestic capital stock plus NFAP) is equal to 1.8% in 1967, which we calculated using the Flow of Funds tables as provided by the FRED Database of Federal Reserve Bank of St. Louis (2021). In the model, we require that the equilibrium interest rate clears the asset market given this NFAP-to-wealth ratio.[9] The resulting interest rate is 3.85%.

Internal Calibration. There are still five parameter values that need to be determined: the two production function parameters, ω and ν, which (given the other parameters) 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 labor income 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

[9] This is a reduced form way of modeling the rest-of-the-world economy. A more structural approach would entail modeling and calibrating the rest-of-the-world economy explicitly, including the frictions that are present in international capital markets. We do not follow this route as such modeling does not provide any new insights regarding the main mechanism of this paper, which links the rise in residual wage risk to the rise in skill premium.

Table 2: Internally Calibrated Parameters for 1967

Parameter	Symbol	Value	Target	Data & SRCE	Source
Production parameter	ω	0.7931	Labor share	0.67	NIPA
Production parameter	ν	0.4495	Skill premium	1.5	HPV
Disutility of labor	ϕ	12.1845	Labor supply	1/3	
Discount factor	β	0.9889	Capital-to-output ratio	1.87	NIPA, FAT
Tax function parameter	χ	0.8746	Gvt. budget balance		

This table reports the benchmark calibration procedure. FAT and NIPA stand for Fixed Asset Tables and National Income and Product Accounts of the U.S. Bureau of Economic Analysis (2021) while HPV stands for Heathcote, Perri, and Violante (2010).

the skill premium in 1967, which is reported to be 1.5 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 a capital-to-output ratio of 1.87, which is perhaps lower than typically used in the literature. This is to account for housing being excluded from both capital stock and output calculation as in Krusell, Ohanian, Ríos-Rull, and Violante (2000) whose elasticity estimates we use. The parameter χ is chosen to clear the government budget constraint in equilibrium. Strictly speaking, χ is not a calibrated parameter, but, for clarity, we include it in Table 2, which summarizes the internal calibration procedure.

4 Changes 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 the other four factors that we expect to be important for the skill premium: the skill-biased technical change, the relative supply of skilled workers, government policies, and international capital flows. The changes in all the factors are reported in Table 1.

4.1 Changes in the Skill Premium and in Wage Risk

The skill premium in the United States rose by a significant margin between 1967 and 2010. Heathcote, Perri, and Violante (2010) use CPS data and compute the skill premium for the period 1967-2005 for males between ages of 25 and 60, working at least 260 hours a year. In subsequent work, they update skill premium data series until 2016. They find that the skill premium has been stable around 1.9 during 2005-2016 period. We will, therefore, use the value of 1.9 when comparing the data with the model.[10]

During the same time period, the U.S. economy also experienced a significant increase in residual wage risk. The panel called 'Residual wage risk' of Table 1 reports the rise in the estimates of the variances of both persistent and transitory shocks provided by Hong, Seok, and You (2019) between 1967 and 2010. Due to high volatility of the estimates over time, we set the 2010 value of each variance parameter to the average of the last five observations (2002, 2004, 2006, 2008, and 2010). The persistence parameter of the AR(1) process and the variance of the initial distribution of the persistent component from which entrants make their initial draws are assumed to be constant over time.

4.2 Changes in Other Factors

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) calculates the historical price of equipment capital in consumption good units. To quantify the decline in the price of equipment across the two steady states, we take the average price over the period 2001-2010 relative to the average price in the period 1967-1976. The price of equipment decreased from the normalized value of 1 to 0.1489 over this period. Since different types of labor have different elasticity

[10] To be more precise, Heathcote, Perri, and Violante (2010) find that the skill premium decreased during the Great Recession to about 1.85 from its 2007 level of 1.9, only to rise again after the crisis to reach the pre-crisis level in 2012, and remained virtually constant since then. This is in line with Autor (2014) who also finds that the skill premium has flattened out after 2005. Since we are interested in long-term trends in the skill premium in this paper, we use the value of 1.9 in model-data comparisons.

of substitution with equipment capital, the decline in the relative price of equipment capital endogeneously implies a change in the skill premium, i.e., skill-biased technical change. In the calculations provided by 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.

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. In 1967, these numbers were substantially larger: 56.7% and 49.9%, respectively. In addition, Ferrière and Navarro (2018) document that the tax parameter τ_l, which represents the progressivity of the U.S. tax system, decreases from 0.124 in 1960's to 0.095 in 2010. Using the Federal Reserve Bank of St. Louis (2021) FRED database, we compute that the U.S. government debt relative to GDP increased from 0.26 in 1967 to 0.60 in 2010. We keep government consumption as a fraction of GDP constant between 1967 and 2010 as it is fairly constant in the data.

International Capital Flows. During the period of interest, the U.S. has gone from being a net lender to a net debtor in international capital markets. More precisely, NFAP as a fraction of U.S. national wealth declined from 1.8% in 1967 to -5.4% in 2010. The equilibrium interest rate in the 2010 steady state is such that the asset market clears given

Table 3: Change in the Skill Premium Between 1967 and 2010

	Data			Model		
	1967	2010	Change	1967	2010	Change
Skill premium	1.500	1.900	0.400	1.500	1.905	0.405

The first two columns in this table report the U.S. skill premium in 1967 and 2010, as computed by Heathcote, Perri, and Violante (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 the 2010 steady states. The last column reports the change in the model generated skill premium between 1967 and 2010.

the 2010 NFAP-to-wealth ratio. The equilibrium interest rate in the model declines from 3.85% in the 1967 steady state to 3.23% in the 2010 steady state (in line with the global decline in capital returns).

5 Quantitative Results

The main purpose of this section is to evaluate the quantitative significance of the rise in residual wage risk on the skill premium using our model. Before doing that, Section 5.1 analyzes to what extent the model can account for the change in the skill premium between 1967 and 2010. We also report the model's success in matching changes in key macroeconomic and cross-sectional moments for the same period. Then, Section 5.2 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. Finally, the rest of the section provides further decompositions and an extension to a model with heterogeneous discount factors.

5.1 Model Fit

To assess the model's fit, we first solve for a stationary equilibrium of the model which corresponds to 1967. We feed in the changes in technology, the relative supply of skilled workers, wage risk, and government policy that are described in Section 4, and solve for the stationary equilibrium of the model that corresponds to 2010. We then compare the model generated changes in the skill premium and other key moments with their empirical counterparts for the period of interest.

Skill Premium. Table 3 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 remarkably well in terms of replicating the level of the skill premium in 2010. Restated in terms of changes, the model replicates the 40 percentage points rise observed in the U.S. skill premium.

The goal of this paper is to assess the quantitative importance of the rise in wage risk for the skill premium over the period from 1967 to 2010. However, to assess the model's performance regarding the fit of the skill premium, we also compute an interim steady state corresponding to 1980 which is calculated by feeding in the changes in the relevant factors between 1967 and 1980. The model implies a modest decline in the skill premium: it decreases from the calibrated value of 1.50 in 1967 to 1.47 in 1980. This is in line with the empirical evidence. In fact, the model implied skill premium is quite close to 1.46, which is the value reported by Heathcote, Perri, and Violante (2010) for 1980. The details regarding the 1980 steady state computations can be found in Online Appendix C.

Macroeconomic Moments. Table 4 summarizes the fit of the model across the two steady states with respect to key macroeconomic moments. For each variable x, the table reports the gross growth rate $\Delta x = x_{2010}/x_{1967}$ in the data and across the two steady states of the model. None of the reported statistics were targeted in the calibration procedure. Output grows by a factor of 2.31 in the model between the 1967 and the 2010 steady states, which matches well the growth experience of the U.S. economy during this period: according to the Federal Reserve Bank of St. Louis (2021) FRED database (series A939RX0Q048SBEA),

Table 4: Growth Rates of Macroeconomic Moments Between 1967 and 2010

	Data	Model	Data Source
	1967 - 2010	1967 - 2010	
ΔY	2.24	2.31	FRED
$\Delta K/Y$	1.12	1.18	NIPA and FAT
$\Delta I/K$	0.84	0.97	NIPA and FAT
$\Delta \frac{qK_e}{qK_e+K_s}$	0.87	0.93	FAT

For each variable x, this table reports the gross growth rate $\Delta x = x_{2010}/x_{1967}$ in the data and across the two steady states of the model. Y stands for real GDP, taken from the Federal Reserve Bank of St. Louis (2021) FRED database series A939RX0Q048SBEA. The changes in the capital-to output ratio K/Y and the investment-to-capital ratio I/K were computed using the National Income and Product Accounts (NIPA), Table 1.5.5 and the Fixed Asset Tables (FAT), Table 1.1 as reported by the U.S. Bureau of Economic Analysis (2021). For these ratios we use non-residential Y, K and I. The share of equipment capital in total capital $\frac{qK_e}{qK_e+K_s}$ is calculated from FAT Table 1.1 using private (non-government) non-residential capital stocks. Because 2010 is a recession year, all the data moments for 2010 are calculated using averages of variables across 2005-2015.

real output per capita grew by a factor of 2.24 between 1967 and 2010. The model somewhat overshoots the increase in the capital-to-output ratio and the decline in the investment-to-capital ratio. The model replicates well the decline in the share of equipment capital in total capital stock.

With respect to other macroeconomic variables of interest, which are not reported in Table 4, the model qualitatively 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 3.85% to 3.23% between 1967 and 2010. The labor share in the model remains roughly constant around 0.67 across the two steady states. Following the methodology in Ríos-Rull and Santaeulàlia-Llopis (2010), we find that in the data the labor share decreases from 0.67 to 0.62. 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).

Finally, in the model, all savings is done at the household level by assumption. 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 gross national savings rate as a fraction of output in the model increases from 18% in 1967 to 21% in 2010. The savings rate increases partly because in the final steady state, the economy needs to service foreign debt repayment (due to the negative net foreign asset position). In the data, the gross national savings rate as a fraction of national income declines from about 23% in 1967 to 18% prior to the Great Recession due to the decline in interest rates associated with foreign capital inflows. Our model would replicate this decline in the savings rate if we modeled the transition in which the U.S. economy goes from being a net foreign creditor to being a net foreign debtor. Since we are interested in the long-run relationship between wage risk and the skill premium, we abstract from these transitional movements in the U.S. capital account.

Cross Sectional Moments. Table 5 summarizes the performance of the model vis-a-vis the data in terms of cross-sectional wage and earnings (defined as labor income before taxes) moments. As Heathcote, Perri, and Violante (2010) note, the 50-10 ratio and the variance of log emphasize the degree of inequality at the bottom half of the distribution, while the 90-50 ratio and the Gini coefficient emphasize the degree of inequality at the top half of the distribution. Inequality at the bottom and the top often evolve quite differently. For this reason, we provide a comparison of both groups of measures between the model and the data. As Table 5 shows, the model does a good job at matching the rise in inequality at both the bottom and top halves of the earnings distribution: for instance, the variance of log earnings increases by 0.41 in the data and 0.36 in the model while the Gini coefficient of earnings increases by 0.11 in the data and 0.14 in the model. The model also matches the rise in inequality at the top half of the wage distribution reasonably well: the Gini coefficient of wages increases by 0.10 in the data and 0.12 in the model.

Table 5 also shows that the model overestimates the rise in inequality in the lower half of the wage distribution. The variance of logged wages increases by 0.19 in the data and 0.28 in the model, the variance of logged residual wages increases by 0.13 in the data and 0.23 in the model, and the 50-10 ratio increases by 0.23 in the data and 0.72 in the model. However,

Table 5: Cross-Sectional Moments in 1967 and 2010

	Data			Model		
	1967	2010	Change	1967	2010	Change
Earnings						
Varlog earnings	0.40	0.81	0.41	0.29	0.65	0.36
Gini earnings	0.35	0.46	0.11	0.29	0.43	0.14
50-10 earnings	2.10	2.97	0.77	2.10	2.77	0.67
90-50 earnings	1.69	2.37	0.68	2.05	3.09	1.04
Wages						
Varlog wages	0.30	0.49	0.19	0.26	0.54	0.28
Gini wages	0.30	0.40	0.10	0.28	0.40	0.12
50-10 wages	2.04	2.27	0.23	2.06	2.78	0.72
90-50 wages	1.78	2.38	0.60	2.06	2.78	0.72
Varlog residual wages	0.26	0.39	0.13	0.24	0.47	0.23
Wealth						
Gini wealth	0.80	0.83	0.03	0.64	0.66	0.02
Top 10%'s share	0.68	0.71	0.03	0.47	0.51	0.04

This table reports the changes in cross-sectional moments between 1967 and 2010. Varlog of variable x stands for the variance of logs of variable x, Gini is the usual Gini coefficient and 50-10 (90-50) of variable x stands for the ratio of the 50th to the 10th (90th to 50th) percentile of the distribution of variable x. Except for wealth statistics, all statistics are taken from Heathcote, Perri, and Violante (2010) and their subsequent work in which they extend their analysis until 2016. These statistics are all for males with the exception of the Gini coefficient for earnings, which is only reported for the main earner in the household by Heathcote, Perri, and Violante (2010). Wealth statistics are taken from the World Inequality Database.

Heathcote, Perri, and Violante (2010), whose data we use, trim about 5% of people at the low end of the wage distribution by dropping people who report wages lower than 50% of the federal minimum wage. When we trim 5% of individuals with the lowest wages from the model generated data (both at the initial and the terminal steady states), the model's fit regarding the changes at the lower end of the wage distribution improves. The variance of log of wages now rises by 0.24, the variance of log of residual wages by 0.18 and the 50-10 wage ratio increases by 0.48.

It is well known that this class of models cannot account for the wealth concentration at the top of the wealth distribution. This is also true for our model. However, the model replicates well the *change* in wealth concentration observed in the data. As the last two rows of Table 5 reports, between the two steady states, the wealth Gini rises by 2 percentage points (from 0.64 to 0.66) as it does in the data (0.80 to 0.83) between 1960 and 2010. The wealth share of top 10% of agents in the wealth distribution rises by 4 percentage points (from 0.47 to 0.51) in the model while in the data this number is 3 percentage points (from 0.68 to 0.71). The data counterparts are taken from the World Inequality Database. In Section 5.5, we consider a less standard version of the model that achieves a better match regarding wealth inequality.

Finally, we also look at what the wage processes we use imply for life-cycle wage volatility. Heathcote, Perri, and Violante (2010) report that over a 35-year-long working life, the variance of logged wages increases by 35 log points when controlling for cohort effects (for the sample period of 1967 to 2000). Our model implies comparable changes in the volatility of wages over the life cycle. The same statistic implied by our model is 23 log points for the skilled and 22 log points for the unskilled at the initial steady state and 54 log points for the skilled and 40 log points for the unskilled at the terminal steady state.

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 that our model generates a reasonable degree of insurance possibilities for agents. In Online Appendix D, we provide a measure of the degree of insurance available in the model and compare it to the empirical literature. In particular, we estimate the pass-through from income shocks to consumption using model generated data, and find that the pass-through coefficients are very close to those estimated by Blundell, Pistaferri, and Preston (2008) using PSID data. The fact that our model generates realistic pass-through values suggests that through endogenous labor supply, progressive taxation and self-insurance the model provides a realistic degree of insurance opportunities.

5.2 Quantitative Significance of the Changes in Wage Risk

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 includes keeping the U.S. NFAP as a fraction of U.S. national wealth unchanged at its 1967 level. 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. The skill premium increases to 1.600 or 10 percentage points in this exercise. This amounts to about 25% of the total 40 percentage points rise in the skill premium between 1967 and 2010.

As an alternative, we feed in the observed changes in all four other factors keeping the structure of wage risk as it was in 1967. This counterfactual economy is called "All but Risk". In particular, the interest rate is set so that the U.S. NFAP as a fraction of U.S. wealth equals its 2010 value in this economy. A comparison of the skill premium in the All but Risk 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. The skill premium is 1.845 in the All but Risk economy, implying a contribution of 6 percentage points coming from the rise in wage risk. This means that about 15% of the total rise in the skill premium between 1967 and 2010 is due to changes in wage risk. We conclude that the rise in wage risk has a quantitatively significant effect on the skill premium.

Online Appendix E shows that this conclusion is robust to various values of the CRRA preference parameter σ and labor supply elasticity parameter γ. Appendix F 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. We find that the effect of the rise in wage risk on the skill premium remains significant when the education decision is endogenous.

The change in wage risk affects the skill premium through the following mechanism. An increase in residual wage risk leads to higher precautionary savings. 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 14%. In the "All but Risk" exercise, the level of equipment capital is about 11% lower than in the exercise in which all factors, including risk, change to their 2010 levels.

The significance of the changes in wage risk for the skill premium 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.

The Role of Other Factors. We also calculate counterfactuals to evaluate the contribution of other factors to the rise of the skill premium. We do so by starting from the 2010 steady state and removing the change in a factor at a time and computing the skill premium in the resulting steady-state economy. The first two rows of Table 6 describe the contribution of each factor starting with what we call the traditional channels, that is the skill-biased technical change and the change in the relative supply of skilled people combined. The table reveals that the traditional channels are the most important determinants of the change in the skill premium, which confirms earlier findings in the literature. Next we remove the change in government policies and calculate the skill premium for this economy. A comparison of the skill premium of this economy with that of the economy where only traditional channels variables are set to their 1967 levels informs us about the contribution of the change in government policy to the rise in the skill premium. Finally, removing also the changes in capital flows, we see that changes in capital flows have also contributed, albeit modestly, to the increase in the skill premium. This finding is in line with the empirical

Table 6: Contribution of Factors to Changes in the Skill Premium

	2010	– Traditional	– Policy	– Capital Flows	– Risk
Skill premium	1.905	1.664	1.614	1.600	1.500
Contribution	–	59.4%	12.4%	3.5%	24.7%

	2010	– Risk	– Capital Flows	– Policy	– Traditional
Skill premium	1.905	1.845	1.840	1.793	1.500
Contribution	–	14.8%	1.2%	11.4%	72.5%

This table reports the contribution of the changes in each factor - wage risk, traditional channels (skill-biased technical change and relative supply of skilled workers), policy, and international capital flows - to the rise in the skill premium by removing the change in a factor at a time and computing the skill premium in the resulting steady-state economy.

results of Larrain (2015) and complements the findings in the international trade literature, namely that trade liberalization leads to increases in economic inequality in general and the skill premium in particular, see e.g. Parro (2013) and Burstein and Vogel (2017). The last two rows of Table 6 report the contributions of the same factors, this time starting with the wage-risk channel first. The contributions of individual factors differ depending on the order in which the changes in factors are introduced due to the non-linear nature of the model.

International Capital Flows. We model the United States as an open economy because part of the rise in aggregate savings, coming from the rise of wage risk, may be absorbed by the rest of the world, implying a smaller increase in aggregate U.S. capital stock, and hence, in the skill premium. In our counterfactual exercises, we model this absorption in reduced form in the sense that the U.S. NFAP as a fraction of U.S. wealth is kept constant before and after the changes in wage risk are introduced. In the Only Risk exercise, this fraction is kept at its 1967 value of 1.8%. This amounts to assuming that 1.8% of the rise in U.S. national wealth coming from the rise in wage risk is absorbed by the rest of the world and does not turn into U.S. capital stock. As a robustness, we check the quantitative strength of our mechanism under an alternative assumption about how the U.S. NFAP changes in response to the changes in wage risk. Specifically, we assume that the U.S. NFAP as a fraction of the U.S. national wealth doubles to 3.6%. This is a relatively high value given that this ratio has never exceeded 3% in the post-war era. The effect of wage risk on the skill premium remains significant under this assumption as well: the skill premium increases to 1.596 in response to the rise in wage risk, which is only slightly smaller than the skill premium of 1.600 under the baseline analysis.

Similarly, in the benchmark All but Risk exercise, the U.S. NFAP as a fraction of its wealth is set to its 2010 value of -5.4% before and after the change in wage risk is introduced. To account for the possibility that the rise in the wage risk could have given rise to substantial net U.S. capital outflows we compute an alternative All but Risk exercise. In this exercise, the NFAP-to-wealth ratio in the All but Risk U.S. economy is set to a substantially smaller number of -10.8% to capture the capital outflows that may occur in response to the rise in wage risk (which brings the 2010 U.S. economy to an NFAP of -5.4%). The skill premium is 1.848 in this All but Risk economy, implying a change of 5.7 percentage points due to the rise in wage risk, instead of the 6 percentage points increase in the benchmark exercise. These findings reassure us about what our benchmark analysis delivers: the change in wage risk is an important driver of the changes in the skill premium.

5.3 Two Decompositions

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

Persistent vs. Transitory Component. The wage processes have two components, a transitory component and a highly persistent component. The variances of both of 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 steady states of the corresponding economies.

Table 7: Decomposition between Persistent and Transitory Components

	1967	2010	Risk overall	Persistent component	Transitory component
Skill premium	1.500	1.905	1.600	1.593	1.512

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 steady state of 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 the skill premia in the steady states of the counterfactual exercises in which we only change the variances of the persistent components and transitory components to their 2010 values, respectively.

The results are reported in Table 7. 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 increase in the variances of the transitory components are larger than those of persistent components (see Table 1). That the persistent component is more important for the skill premium is expected, since self-insurance via precautionary savings allows for better intertemporal consumption smoothing against transitory shocks relative to persistent shocks, see Deaton (1992). The increase in persistent shock variances then implies larger precautionary savings responses.

Wage Risk of Skilled vs. Unskilled Agents. Table 8 reports the results for the second decomposition exercise. The column entitled 'Skilled only' displays that the skill premium increases to 1.531 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 larger effect on the skill premium. As shown in Table 1, the rise in wage risk faced by skilled and unskilled agents' (in particular, the volatility of the persistent component, which is more important for the skill premium as discussed above) is of similar magnitude. The fact that the change in unskilled wage risk is more important for the skill premium follows from the fact that there are many more unskilled agents in the economy and that the precautionary savings motive may be more important for the unskilled agents who are poorer in general.

Table 8: Decomposition Between Changes in Skilled and Unskilled Risk

	1967	2010	Risk overall	Skilled only	Unskilled only
Skill premium	1.500	1.905	1.600	1.531	1.563

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 steady state of 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 the skill premia in the steady states of the counterfactual exercises in which we change wage risk parameters to their 2010 values only for skilled agents or unskilled agents, respectively.

5.4 Household Level Risk

We model the United States as a set of single-earner households. In reality, some households have two (or more) earners. The quantitative significance of our main mechanism could be affected if household level income risk evolved differently from individual income risk. If household level risk increased more (less) than individual level risk, then our model would underestimate (overestimate) the rise in precautionary savings, and thus, the strength of the main mechanism.

Household level risk has changed due to factors we model (individual income risk and changes in the skill premium) as well as due to changes in the family structure, which we do not model. These changes are as follows. (i) There was a large increase in female labor force participation as a result of which the fraction of two-earner households among married households increased from 59% in 1967 to 73% in 2010, see Heathcote, Perri, and Violante (2010). Taking this factor into account might dampen the income risk households face. (ii) The share of married households among all households declined from 80% to 56% due to the decline in marriage rates and the rise in divorce rates (see Greenwood, Guner, Kocharkov, and Santos (2016)), which limits the intra-family insurance against income risk at the aggregate level. (iii) There was a rise in the degree of assortative matching in the marriage market (see Greenwood, Guner, Kocharkov, and Santos (2016)), which presumably amplified the income risk households face. It is an empirical question whether these three changes combined imply that household level risk increased more or less than individual level risk, i.e., whether the strength of intra-family income insurance decreased or increased between 1967 and 2010. Using household level earnings and consumption data, Blundell, Pistaferri, and Preston (2008) find that the degree of household consumption insurance with respect to household level income shocks did not change in the United States in the 1980s and early 1990s. This suggests that the overall effect of the changes in the family structure on insurance against wage shocks might be limited.

5.5 Role of Wealth Inequality

The main model we use to investigate the link between rising wage risk and the skill premium, introduced in Section 2, is intentionally chosen to be a standard incomplete market model used widely in the macroeconomics literature. Although this model has a solid performance in matching some moments of the overall wealth inequality, it is well known in the literature that it can fall short of generating the amount of inequality present especially in the tails of the wealth distribution. Given the possible heterogeneity regarding the marginal propensities to save across the wealth distribution, this can affect the strength of the mechanism proposed in this paper. In this section, we present a less standard version of the incomplete market model with heterogeneity in discount factors (and a positive borrowing limit) that achieves a better match regarding wealth inequality. We find that changes in wage risk imply significant changes in the skill premium in this version of the model as well.

To match wealth inequality, we extend the baseline model along two dimensions. First, we allow for discount factor heterogeneity both across skill types and within each skill group, an idea similar to Krusell and Smith (1998). We allow for two discount factor types with equal population weights within each skill group. We calibrate the four discount factors to match the capital-to-output ratio (as in the baseline model) and three inequality moments: the ratio of average skilled wealth to average unskilled wealth, the Gini coefficient of the wealth distribution for the skilled workers, and the Gini coefficient of the wealth distribution

Table 9: Cross-Sectional Wealth Distribution Moments in 1967 and 2010

	Data			Model		
	1967	2010	Change	1967	2010	Change
Wealth Gini (skilled)	0.75	0.79	0.04	0.75	0.79	0.04
Wealth Gini (unskilled)	0.77	0.81	0.04	0.77	0.81	0.04
Skilled-unskilled wealth	3.35	5.10	1.75	3.35	5.10	1.75
Wealth Gini	0.80	0.83	0.03	0.79	0.84	0.05
Top 10%'s share	0.68	0.71	0.03	0.64	0.73	0.09

This table reports the changes in cross-sectional moments between 1967 and 2010. Gini is the usual Gini coefficient and skilled (unskilled) wealth Gini is the Gini coefficient for the distribution of wealth among skilled (unskilled) agents. Skilled-unskilled wealth corresponds to the ratio of the total wealth of skilled agents to that of unskilled agents. Wealth Gini for the skilled and the unskilled agents and the skilled-unskilled wealth ratio are taken from Kuhn and Rios-Rull (2016). For these three variables, the data values for 1967 corresponds to year 1989, the earliest that they report. Wealth Gini and Top 10%'s share are taken from World Inequality Database.

for the unskilled workers. We calibrate the discount factors both in the 1967 and 2010 steady states in order to match not only the levels but also the changes in these moments.

Second, borrowing is ruled out in the benchmark model. To match bottom wealth inequality, we now assume that borrowing is allowed, but limited by an exogeneous upper bound. We follow Heathcote, Storesletten, and Violante (2010) and calibrate the exogenous borrowing limit so that in the initial steady state the fraction of people with negative wealth in our model is 15%, which approximates the corresponding data moment. This exogenous limit is held constant in the '2010', the 'Only Risk' and the 'All But Risk' exercises. The rest of the calibration procedure of this version of the model is similar to the calibration of the baseline model. The details can be found in Online Appendix G.

The first three rows of Table 9 show that the model hits calibration targets exactly. Regarding non-targeted moments, the penultimate row displays that the model is successful in matching the Gini coefficient of the overall wealth distribution in 1967 and 2010. The last row shows that the model overestimates the change in the concentration of wealth at the top of the distribution.

The results regarding the skill premium are reported in Table 10. As the second column shows, the model delivers a good fit in terms of the overall increase in the skill premium:

Table 10: Effect of Wage Risk on the Skill Premium with Heterogeneous Discount Factors

	1967	2010	Only Risk	All but Risk
Skill premium	1.500	1.879	1.582	1.853
Contribution			22.5%	6.8%

The first two columns report the skill premia in the 1967 and the 2010 steady states. The column 'Only Risk' reports the value of the skill premium in the steady state of the counterfactual exercise where wage risk parameters are set to their 2010 values but all the other factors remain at their 1967 values. The column 'All but Risk' reports the value of the skill premium in the steady state of the counterfactual exercise where wage risk parameters remain at their 1967 values but all the other factors are set to their 2010 values.

38 vs. 40 percentage points. Depending on the counterfactual analysis, the rise in wage risk generates about 8 percentage points rise in the skill premium in the Only Risk exercise (from 1.500 to 1.582) and 3 percentage points rise in the All but Risk exercise (from 1.853 to 1.879). The contribution of the rise in wage risk to the rise of the skill premium is smaller than in the baseline model. This is because the heterogenous discount factor model generates a higher concentration of wealth at the top of the wealth distribution where the precautionary savings motive is weaker. Importantly, the change in wage risk remains a quantitatively significant determinant of the skill premium in this extended version of the model.

6 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 significantly in virtually 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.

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