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.
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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 individuals face uninsured idiosyncratic wage risk. Capital-skill complementarity is built in by assuming a production function that

[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).

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 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 three 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 modelled as a decline in the price of equipment. The third factor that changes between 1967 and 2010 is government policy. Having introduced changes in the structure of wage risk, technology, relative supply of skilled workers, and government policy, we solve for the new steady state, which corresponds to 2010.

The model generates a 41 percentage point increase in the skill premium, from 1.50 in 1967 to 1.91 in 2010. In the data, the U.S. skill premium increases by about 40 percentage points to 1.90 in 2010.[4] In addition, the model matches well the trends in main macroeconomic and distributional moments between 1967 and 2010. 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

[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. In subsequent work, they extended the skill premium series until 2016. We are grateful to Jonathan Heathcote for sharing their findings with us.

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 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 and government policy that is 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 1.85, which is 6 percentage points shy of the model implied skill premium for 2010.[5] A comparison of these numbers to the observed 40 (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 agents' risk aversion, elasticity of labor supply, 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 6 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. 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.

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

[5] The fact that the two counterfactuals attribute different magnitudes to the importance of wage risk (10 vs. 6 percentage points) alludes to the significant non-linearities present in the model.

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.

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 (2017) 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). 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 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 (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.[7]

[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.

[7]The finding that wage risk has increased in the United States in the last few decades has been challenged

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 skill premium, wage risk and other factors between 1967 and 2010. Section 5 discusses our main quantitative findings. In Sections 6 and 7, we consider two extensions to the basic framework: an extension in which people's skill supply is endogeneous and an open economy extension with international trade in goods and capital. Section 8 concludes. The Appendix contains the equilibrium definition used in the paper and the details of our empirical calculations.

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

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).

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. 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 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 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. 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. Structure and equipment capital depreciate at rates δ_s and δ_e, 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 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. 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 $T_t(y)$ 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 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 consumers' problem. Consumer's (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 5.6 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.

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, instead of giving a general definition of competitive equilibrium, we only define stationary recursive competitive equilibria (SRCE). The definition is relegated to Appendix A.

3 Calibrating the Model to 1967

In order to evaluate the quantitative significance of our mechanism, 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. 1967 is chosen as the initial steady state 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 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.

Table 1: Benchmark Parameters

Parameter	Symbol	1967	2010	Source
Preferences				
Relative risk aversion parameter	σ	2	2	
Inverse Frisch elasticity	γ	2	2	
Probability of death	δ	0.022	0.022	
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
Fraction of skilled workers	π_s	0.1356	0.3169	CPS
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	0.25	0.32	FRED

This table reports the benchmark parameters taken 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, D, FN, G, GHK, HSV, HSY, and KORV stand for Auerbach (1983), 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 Current Population Survey, the Federal Reserve Bank of St. Louis FRED database, and National Income and Product Accounts, respectively.

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.[8] 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 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. 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 (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

[8] 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 $\log(c) - \phi\frac{l^{1+\gamma}}{1+\gamma}$.

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 1970-2012, as reported in the National Income and Product Accounts (NIPA) data. We set the government debt-to-GDP ratio to 25% for 1967 as reported by the Federal Reserve Bank of St. Louis FRED 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. See Appendix B for the details of the data construction.

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.[9] 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, 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 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.

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 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

[9] 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 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 in 1967	1.5	CPS
Disutility of labor	ϕ	12.1845	Labor supply	1/3	
Discount factor	β	0.9889	Capital-to-output ratio	2	NIPA, FAT
Tax function parameter	χ	0.8746	Gvt. budget balance		

This table reports the benchmark calibration procedure. CPS, FAT and NIPA stand for Current Population Survey, Fixed Asset Tables and National Income and Product Accounts, respectively.

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 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 2, 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. Finally, 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 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. 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

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.

[10]To be more precise, Heathcote, Perri, and Violante (2010) find that the skill premium has 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 data comparison.

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.[11] 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 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 while in 1967 the numbers were substantially larger; 56.7% and 49.9%. 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 1967 to 0.095 in 2010. Using the Federal Reserve Bank of Saint Louis FRED database,

[11] We use an updated version of DiCecio's work, which is available in the Federal Reserve Bank of Saint Louis FRED database.

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

	Data			Model		
	1967	2010	Change	1967	2010	Change
Skill premium	1.50	1.90	0.40	1.50	1.91	0.41

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.

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.

5 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 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 robustness exercises.

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 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 one percentage point. Restated in terms of changes, the model replicates the rise in the skill premium well: 40 percentage points in the data vs. 41 percentage points in the model.

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 2.32 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 database (series A939RX0Q048SBEA), real output per capita grew by a factor of 2.18 between 1967 and 2010. The fit would be even better if year 2010 was not a recession year. The model somewhat overshoots the increase in the capital-to-output ratio and the decline in the investment-to-capital ratio, the latter again due to the Great Recession. 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

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

	Data	Model	Data Source
	1967 - 2010	1967 - 2010	
ΔY	2.18	2.32	FRED
$\Delta K/Y$	1.13	1.19	NIPA and FAT
$\Delta I/K$	0.79	0.97	NIPA and FAT
$\Delta \frac{qK_e}{qK_e+K_s}$	0.87	0.92	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 FRED database series A939RX0Q048SBEA. The changes in the capital-to output ratio K/Y and the investment-to-capital rato 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. 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.

in recent decades: in the model, the annual real return on government bonds decreases from about 3.3% to 2.6% between 1967 and 2010. The labor share in the model remains roughly constant across the two steady states. 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). 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 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.

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, 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 know 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: between the two steady states, the wealth Gini rises by 3 percentage points (from 0.64 to 0.67) whereas in the data it increased by 2 percentage points (0.80 to 0.82) between 1960 and 2010. The wealth share of top 10% of agents in the wealth distribution rises by 5 percentage points (from 0.47 to 0.52) in the model while in the data this number is 3 percentage points (from 0.71 to 0.74). The data counterparts are taken from Kaymak and Poschke (2016).

Finally, we also look at what the wage processes we use imply for life-cycle wage volatil-

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	2.76	0.66
90-50 earnings	1.69	2.37	0.68	2.07	3.12	1.05
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

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. All statistics are taken from Heathcote, Perri, and Violante (2010). All statistics are 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).

ity. 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 22 log points for both the skilled and the unskilled at the initial steady state and 52 log points for the skilled and 38 log points for the unskilled at the terminal steady state.

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 counterfactual exercise is called "Only Risk". A comparison of the skill premium of this economy with the skill premium in 1967

Table 6: Model Implied Effects of Changes in Wage Risk on the Skill Premium

	1967	2010	Only Risk	All but Risk
Skill premium	1.50	1.91	1.60	1.85
Change			0.10	0.06

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.

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 6 shows that the increase in wage risk has a quantitatively significant effect on the skill premium. Depending on the counterfactual analysis, the rise in wage risk generates 10 or 6 percentage points increase in the skill premium. This amounts to 25% or 15% of the total 41 percentage points rise in the skill premium between 1967 and 2010 that the model predicts.[12]

The change in wage risk affects the skill premium through the following mechanism. An increase in residual wage risk leads to higher precautionary savings.[13] 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

[12]We perform two additional counterfactual exercises. 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 to its 2010 value. The resulting skill premium is 0.57. In the second exercise, we solve for a steady state in which we only change the price of equipment to its 2010 value. The resulting skill premium is 3.84. These results confirm that skilled-biased technical change and the rise in the supply of skilled workers have individually been the most important determinants of the skill premium.

[13]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.

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 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 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

Table 7: Decomposition between Persistent and Transitory Components

	1967	2010	Risk overall	Persistent component	Transitory component
Skill premium	1.50	1.91	1.60	1.59	1.51

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 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.

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.

5.3 Two Decompositions

To shed more light at 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 8: Decomposition Between Changes in Skilled and Unskilled Risk

	1967	2010	Risk overall	Skilled only	Unskilled only
Skill premium	1.50	1.91	1.60	1.53	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 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 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.

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 1.53 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 skill premium follows from the fact that there are many more unskilled agents in the economy.

Table 9: Risk Aversion

σ	1967	2010	Only Risk	All But Risk
1	1.50	1.87	1.54	1.85
2	1.50	1.91	1.60	1.85
3	1.50	1.95	1.68	1.84

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 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 first and third rows report the same set of values for $\sigma = 1$ and $\sigma = 3$ cases.

5.4 Sensitivity to Risk Aversion

The link between the wage risk and the skill premium works through precautionary savings in the proposed mechanism. It is then natural to expect 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 9.

Each row in Table 9 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 the $\sigma = 1$ case falls somewhat short of explaining the overall rise of the skill premium, the $\sigma = 3$ model overshoots this rise. The last two columns show that the effect of the rise in wage risk on the skill premium increases as the risk aversion parameter increases.

5.5 Sensitivity to Elasticity of Labor Supply

This section analyzes the robustness of our results with respect to the elasticity of labor supply. Given our preference choice, the elasticity of labor supply in the model is given by

Table 10: Elasticity of Labor Supply

$1/\gamma$	1967	2010	Only Risk	All But Risk
0.25	1.50	1.89	1.60	1.84
0.5	1.50	1.91	1.60	1.85
0.75	1.50	1.90	1.60	1.85

The second row of the table reports skill premia in the model for the benchmark analysis with $\gamma = 2$. 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 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 first and third rows report the same set of values for $\gamma = 4$ and $\sigma = 4/3$ cases.

$1/\gamma$. In the benchmark exercise, we use $\gamma = 2$, which implies a labor supply elasticity of 0.5 and is reported in the middle row of Table 10. The last row of the table reports our findings for a higher labor supply elasticity of 0.75 as suggested by Chetty, Guren, Manoli, and Weber (2011) while the first row reports them for a lower elasticity level. We find that our results are robust to a wide range of labor supply elasticity values.

5.6 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', the 'Only Risk' and the 'All But Risk' exercises. A comparison of the two rows of Table 11 shows that the main quantitative results are not affected by the presence of borrowing constraints.

Table 11: Skill Premium With and Without Borrowing

	1967	2010	Only Risk	All But Risk
No borrowing, $a \geq 0$	1.50	1.91	1.60	1.85
Borrowing, $a \geq -\bar{a}$	1.50	1.91	1.60	1.85

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, 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 first row of the table reports skill premia for the benchmark economy without any borrowing. The second row reports skill premia for an alternative economy in which agents are allowed to borrow up to an exogeneous limit $\bar{a}$.

5.7 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 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 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.

A more indirect way of gauging the effect of how changes in the family structure affected the evolution of household level risk relative to individual level risk is to compare the evolution of household level inequality to individual level inequality. Heathcote, Perri, and Violante (2010) find that the variance of logged household earnings follows a very similar pattern to the variance of logged individual earnings between 1967 and 2010: they both increase from 0.52 to 0.85. Similarly, the rise in the Gini coefficient of earnings is quite similar for households and main-earners. The former increases from 0.34 to 0.43 while the latter increases from 0.35 to 0.46. The fact that the evolution of the cross-sectional earnings' inequality measures is quite similar between the household and main-earner samples suggests that the effect of the changes in family structure on our mechanism is limited. In fact, using a structural model, Greenwood, Guner, Kocharkov, and Santos (2016) argue that changes in the family structure have acted as an amplification mechanism from individual level income inequality to household level income inequality. Using household level income shocks that are larger than individual level shocks would make our main mechanism quantitatively stronger.

6 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 are 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. We find that the effect of the rise in wage risk on the skill premium remains significant when the education decision is endogenous.

6.1 Model with Endogenous Skill Supply

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 become skilled agents or a lower level of education, in which case they become unskilled agents. 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 $H(\psi)$. 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

Table 12: Endogenous Skill Supply

			Exogenous		Endogenous	
	1967	2010	Only Risk	All but Risk	Only Risk	All but Risk
Skill premium	1.50	1.91	1.60	1.85	1.57	1.87
Change		0.41	0.10	0.06	0.07	0.04
Fraction skilled	13.56%	31.69%	13.56%	31.69%	13.81%	31.35%

This table reports the skill premium along with the fraction of skilled agents in the model economy. The first and second columns report these variables for the 1967 and the 2010 steady states. The first column of the panel 'Exogeneous' reports these variables for the counterfactual exercise in which only wage risk changes in the benchmark exogenous skill supply economy ('Only Risk'). The second column of that panel reports them for the counterfactual exercise in which all factors are set to their 2010 values but wage risk parameters are at their 1967 values ('All but Risk'). The panel 'Endogeneous' report the values of the same set of variables for the endogenous skill supply economy. Numbers may not add up due to rounding.

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 endogeneous 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, $h(\psi) = me^{-m\psi}$, and a cdf, $H(\psi) = 1 - e^{m\psi}$. For the marginal agent who chooses to go to college, the cost of attending college exactly equals the benefit of doing so, $\bar{\psi} := E_{s,0}[V_s(z_s,0)] - E_{u,0}[V_u(z_u,0)]$. The total measure of agents who face an education cost that is at most $\bar{\psi}$ is equal to 0.1356 in 1967. Thus, we calibrate m by setting $H(\bar{\psi}) = 0.1356$.[14]

[14]The quantitative results are almost identical if, instead of being exponential, the utility cost distribution H is assumed to be uniform $U[0,m]$ and one calibrates m to the same target, i.e. so that $H(\bar{\psi}) = 0.1356$.

6.2 Results

The result of the "Only Risk" counterfactual exercise under endogenous skill supply is reported in the penultimate column of Table 12. For comparison purposes, the table also reports the same exercise for the benchmark case with exogenous skill supplies in the third column of Table 12. The effect of the rise in wage risk on the skill premium is smaller in the endogenous skill supply exercise (7 vs. 10 percentage points). This happens because when the skill premium increases in response to rise in wage risk, a higher fraction of the population attends college (13.81% vs. 13.56%), which then dampens the rise of the skill premium. We obtain a similar result when we consider the "All but Risk" counterfactual exercise. With endogenous skill supply, the effect of wage risk on skill premium is 4 percentage points, which is smaller than 6 percentage points, its effect in the case of exogenous skill supply.

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 that the main mechanism is still 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 mechanism 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).[16] The two economies are linked only through frictionless capital and goods markets; there is no labor mobility across the two countries. Incorporating the frictions that are present in actual international capital markets would bring the U.S. economy closer to the closed economy benchmark which would increase the strength of our mechanism.

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

[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).

[16] If the rest of the world was modelled as a representative agent economy, the world interest rate in any steady state would be pinned down solely by the rest-of-the-world discount factor, implying that the elasticity of the steady-state world interest rate with respect to U.S. savings would be zero. As a result, even a permanent change in U.S. saving behavior (coming, for instance, from a permanent change in the structure of U.S. wage risk) would be fully absorbed by the rest-of-the-world economy without any impact on the world interest rate in the long run. This scenario would obviously fall short of capturing the importance of the United States in world financial markets. Furthermore, under this scenario, it is immediate that a change in U.S. wage risk has virtually no bearing on U.S. capital accumulation, and hence, the U.S. skill premium.

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

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.[17] 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-Douglas production function

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

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

[17]The savings glut hypothesis was first put forth by Bernanke (2005). We follow Kehoe, Ruhl, and Steinberg (2018) in modelling the savings glut as a change in foreigners' savings wedge.

and $I\hat{I}P$ denote the net international investment positions of the United States and rest of the world economies respectively, the market clearing for the 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 positions 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%.[18]

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, UK, France, and Italy, as estimated by LeBlanc and Georgarakos (2013). These

[18]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 3. 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 2010 closed economy model.

Table 13: 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	$\hat{\beta} = \beta\delta$	0.9676			
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	$\hat{A}$	0.1731	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	2.66%	U.S. IIP/U.S. GDP	-16.3%	NIPA
R.O.W. savings wedge	$\hat{\psi}$	0.9155	R.O.W. IIP/U.S. GDP	16.3%	NIPA
R.O.W. TFP	$\hat{A}$	0.3119	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.

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 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, $\hat{\psi}$, and the total factor productivity (TFP), $\hat{A}$, 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 2.66% (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, $\hat{\psi}$, and the TFP in the rest of the world, $\hat{A}$, 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 13 and the details of our empirical calculations are contained in Appendix B. Notice that the rest-of-the-world savings wedge, $\hat{\psi}$, increases between 1967 and 2010. This rise is the model's way of generating the savings glut.

7.3 Quantitative Significance of the Rise in U.S. Wage Risk

In this section, 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. Table 14 summarizes our results. The second column of the table informs us that the value of the skill premium in 2010 is 1.9, which implies that the open economy model is equally successful as the benchmark closed economy model in replicating the observed rise in the skill premium during the period of interest.[19]

[19] This may seem surprising because the open economy model takes into account the fact that the assets held in the U.S. economy by foreigners increase substantially (from -10% to 16.3% 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

Table 14: Open Economy Decomposition

	1967	2010	Only Risk	Risk + Savings glut	All but Risk
Skill premium	1.50	1.90	1.55	1.57	1.88
Change			0.05	0.07	0.03

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 column 'All But Risk' reports the skill premium in the counterfactual 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', the 'Risk + Savings glut' and the 'All But Risk' 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.

The third column of Table 14 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 5 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 7% (relative to the 15% in the closed economy exercise).

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 14 shows that the rise in wage risk increases the skill premium by 7 percentage points in this

to the capital-skill complementarity. This does not happen, however, because the inflow of foreign savings crowds out domestic savings and, hence, does not increase the U.S. capital stock and the skill premium.

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. Finally, we also compute an "All but Risk" exercise in which we change all the variables to their 2010 values except for wage risk. We find that in this case the model falls 3 percentage points short of explaining the change in the skill premium.

7.4 Open Economy with Endogenous Skill Supply

Both the open economy and the endogeneous education extensions leave the main mechanism quantitatively significant, but each reduces its strength. A natural question is: what if these extensions are considered jointly? To that end, we use the open economy version of the model calibrated to 1967 and perform the 'Only Risk' exercise with endogenous education, as discussed in Section 6. The skill premium increases from its 1967 calibrated value of 1.50 to 1.55, which is virtually the same increase as in the open economy 'Only Risk' exercise. That is, the introduction of the endogenous skill margin to the open economy model does not reduce the rise in the skill premium in response to change in wage risk. This is so because, unlike in the closed economy, in the open economy the rise in the skill premium does not increase the fraction of the population attending college. In fact, the fraction of skilled decreases slightly from 13.56% to 13.54%. This happens because in the 'Only Risk' open economy steady state, U.S. citizens are substantially richer since they are able to save at a higher (world) interest rate. This pure wealth effect makes college attendance less attractive, offsetting the incentives to go to college coming from higher skill premium. We conclude that even when considered jointly, the two extensions leave the main mechanism quantitatively significant.

8 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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Appendix

A Stationary Recursive Competitive Equilibrium

In order to define a stationary equilibrium, government policies (expenditure, debt and taxes) are assumed not to change over time.

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 $s_i = (\mathbf{z_i}, a) \in \mathcal{S}_i = \mathcal{Z}_i \times \mathcal{A}$. Let $\mathcal{B}_{\mathcal{S}_i} = \mathcal{B}_{\mathcal{Z}_i} \times \mathcal{B}_{\mathcal{A}}$ be the Borel $\sigma-$algebra of the set $\mathcal{S}_i$.

Definition. Stationary Recursive Competitive Equilibrium 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 $i \in \{u, s\}$:

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

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

2. The firm solves:

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

3. The distribution λ_i is stationary for each type, i.e. $\forall i = \{s, u\}, \forall s_i \in \mathcal{S}_i, \forall S_i = Z_i \times A \in$

$\mathcal{B}_{\mathcal{S}_i}$, λ_i satisfies

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

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:

$$\begin{aligned} \sum_{i=u,s} \pi_i \int_{\mathcal{S}_i} a_i'(s_i) d\lambda_i(s_i) &= K_s + K_e + D, \\ \pi_i \int_{\mathcal{S}_i} z_i l_i(s_i) d\lambda_i(s_i) &= L_i, \quad \forall i \in \{s, u\}, \\ C + G + K_s + K_e &= F(K_s, K_e, L_s, L_u) + (1-\delta_s) K_s + (1-\delta_e) K_e, \end{aligned}$$

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.

B Data Construction

B.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, with subsequent work extending the series to 2016. They focus on the population of working age males aged 25-60 with at least 260 working hours per year. They drop individuals 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) and individuals whose hourly wage rate is less than half of the federal minimum wage.

B.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 for the decade 1967-1976 and recover the corresponding value for 2001-2010. These values are used for the two setady states representing 1967 and 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).

B.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" reports 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 1.1.5 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

Table 15: 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.

as reported by the U.S. International Trade Administration. Table 15 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 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.